# 3D ELECTRON DENSITY RECONSTRUCTION FROM THE SECCHI CORONAGRAPHS and EUVI ONBOARD STEREO

**Jeffrey Newmark, John Cook**

**Naval Research Laboratory**

**(202) 767-0244**

**newmark@nrl.navy.mil**

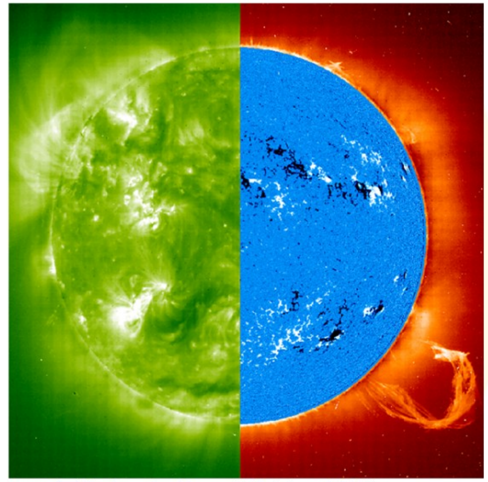
# Outline

- SECCHI 3D Reconstruction and Visualization Website:
  - http://stereo.nrl.navy.mil/3drv/3dindex.html
- Presentation Based on SECCHI Consortium Meeting, April 2004, CA
- Overview of 3D related activities by consortium
- Details of selected activities
- Heliospheric Imager – overview, science planning, CMEs
- SMEI – not STEREO, early results, prelude for HI
- Conclusions

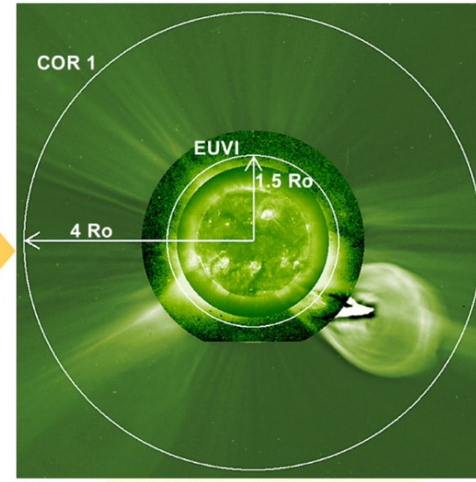
# SECCHI Science Overview

## SECCHI Exploration of CMEs and the Heliosphere on STEREO

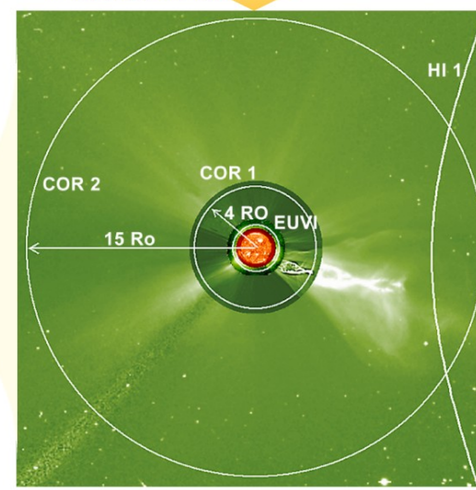
- *What Configurations of the Corona Lead to a CME?*
- *What Initiates a CME?*
- *What Accelerates CMEs?*
- *How Does a CME Interact With the Heliosphere?*
- *How do CMEs Cause Space Weather Disturbances?*



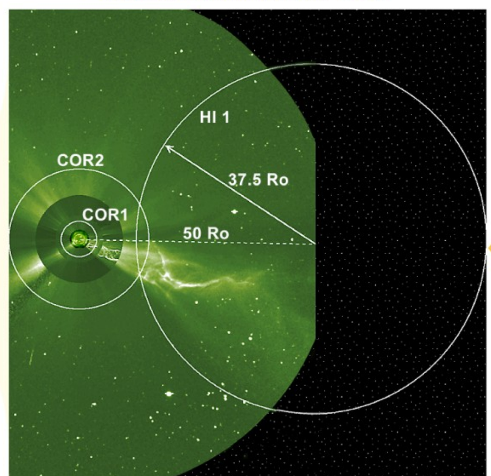
Explore the Magnetic Origins of CMEs
- Photospheric Shearing Motions
- Magnetic Flux Emergence
- Magnetic Flux Evolution and Decay



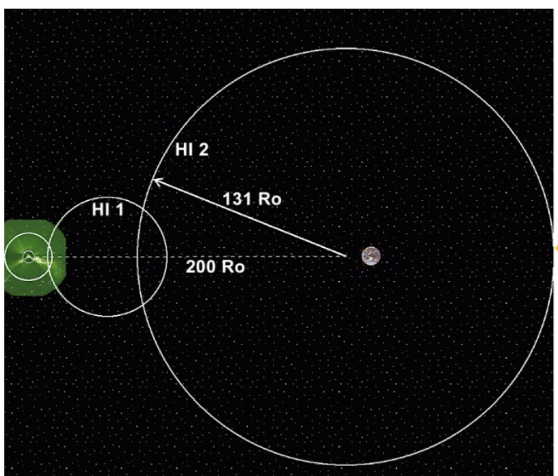

Understand the Initiation of CMEs
- Reconnection
- The Role of Plasma vs. Magnetic Field Effects
- Rapid vs. Slow Drivers




Study the Physical Evolution of CMEs
- Reconnection
- Continued Energy Input and Mass Ejection
- Effect on Helmet Streamers




Investigate the Interaction of CMEs With the Heliosphere
- CME Physical Signatures at 1 AU
- Generation of Shocks
- Acceleration of Charged Particles
- Interaction With Heliospheric Plasma Sheet & Co-Rotating Interaction Regions
- Interaction With Other CMEs




The Sun-Earth Connection: Understand the Role of CMEs in Space Weather
- Observe Trajectory of Earth-Directed CMEs
- Predict Arrival Time and Geo-Effectiveness of CMEs

# Methodologies

- **MHD modeling**
- **Forward Fitting**

- Requires parameterization of model
- Number of parameters could be large
- 2D projection is given, only 3D coordinates need to be constrained by 2nd STEREO image
- Strategy: develop tool with automated 2D-parameterization of curvi-linear features (loops, filaments, fluxropes, sigmoids, postflare loops, etc.)
- 3D coordinate can be first constrained by a-priori model (potential field, force-free, simple geometries, and then iteratively refined with projections from 2nd image, starting with the most unique and unambigous tie-points.
- Examples: Stereoscopy (most suitable for EUVI early in the mission), inclusion of magnetic field

- **Inversion**
  - Inversions generally are coarse because of data noise, ambiguities, non-uniqueness
  - Advantage of inversions: they are model-independent, non-parametric
  - Examples: Tomography, Pixon reconstruction
- **Combination -** None, one, or both methods yield a good fit to data,
  → disproves both models, confirms one model, or ambiguous choice

# SECCHI Group Activities (1)

- NRL
  - 3D Reconstruction of White Light Coronagraph Images from Multiple Viewpoints – Cook, Newmark, Reiser, Yahill – Tomography, Pixon reconstruction, 3D data cube rendering
  - Differential Emission Measure (DEM) Tool for EUVI – Cook, Newmark – comparison with forward fitting models
  - Streamer Simulation – Vourlidas, Marque, Howard, Thernisien – model comparison to data, 3D data cube rendering
  - CME Mass and Energetics Toolbox – Vourlidas, Thernisien, Howard – based on LASCO tools
- JPL
  - Tie Point Tool – De Jong, Liewer, Hasll, Lorre – manual stereoscopy
  - SynLOS: synthetic LOS Tool for SECCHI white Light Images – Liewer, Hall, Lorre – 3D data cube rendering
- LMSAL/Rice
  - 3D Reconstruction of Stereoscopic Images from EUVI – Aschwanden, Lemen, Wuelser, Alexander – forward modeling and constraint time series

# SECCHI Group Activities (2)

- ROB
  - Computer Aided CME Tracking (CACTus) – Robbrecht, Berghmans, Lawrence, Van der Linden – pipeline processing automated CME catalog – based on LASCO – not reconstruction tool presently
  - Computer Aided EIT Wave and Dimming Detection – Podladchikova, Berghmans, Zhukov - pipeline processing automated EIT waves and dimming regions catalog – based on EIT – not reconstruction tool presently
  - Solar Weather Browser (SWB) – Nicula, Berghmans, Van der Linden – browse tool, not reconstruction tool presently
  - (Apparent) Velocity Map Construction – Hochedez, Gissot – full motion analysis software of EUV and WL using optical flow techniques – tracking, detection, stereoscopic reconstruction
- MPS (formerly MPAe)
  - Finite Element Tomography Code (FETOC) – Inhester – 3D tomography inversion code – coronal magnetic filed model can be used as a constraint
  - Stereoscopy of EUV loops – Portier-Fozzani (Athens), Inhester – parameterized, forward fitting loop model
  - Reconstruction of coronal magnetic fields (LINFF, NONLINFF) – Wiegelmann, Inhester – 3D coronal magnetic field from boundary data, interfaces to provide reconstructed field for stereoscopy and tomography

# SECCHI Group Activities (3)

- MPS/UB cont.
  - Real-time and 3D visualization of STEREO images – Bothmer, Kraupe, Schwenn, Podlipnik, Cremades, Wiegelmann – planetarium display
  - 3D Structure of CMEs: Origin, Internal Magnetic Field Configuration and Near-Sun Evolution – Bothmer, Cremades, Tripathi – comparison of model prediction (magnetic field + H-alpha based) and data
- JHU/APL – Automatic solar feature recognition and classification – Rust, Bernasconi, LaBonte – solar filaments, sigmoids, chirality, and CMEs – EUVI – helicity is important for 3D modeling
- Obs. de Paris – Combining Nancay Radio heliograph with SECCHI instruments – Pick, Kerdraon – identification of emitting coronal structures, source regions
- SMEI (not SECCHI, but related to HI) - Jackson, Tappin, Hick, Webb – IPS and Thomson scattering Modeling/Tomography – solar wind model dependent, low resolution, developed from techniques based on Helios data

# SECCHI Group Activities: MHD Modeling

- **NRL – Klimchuk, Antiochos, DeVore, Karpen, Lopez-Fuentes, Lynch, MacNeice, Magara, Patsourakos**
  - **MHD CME initiation and propagation, Coronal loop structure, Coronal heating, Loop plasma evolution (incl. Prominences), Coronal hole evolution, Flux emergence, Active region structure**
  - **3D Visualization - Heliospace package, Developed with ARL (Tim Hall), Based on FAST (NASA/Ames)**
- **SAIC – Mikic, Linker, Riley, Lionello – coronal and Heliospheric timde dependent MHD model = MAS**
- **Univ. Alabama – Wu – MHD models**
- **GSFC CCMC – hosts models**

# Specific Examples

# NRL 3D WL: Reconstruction

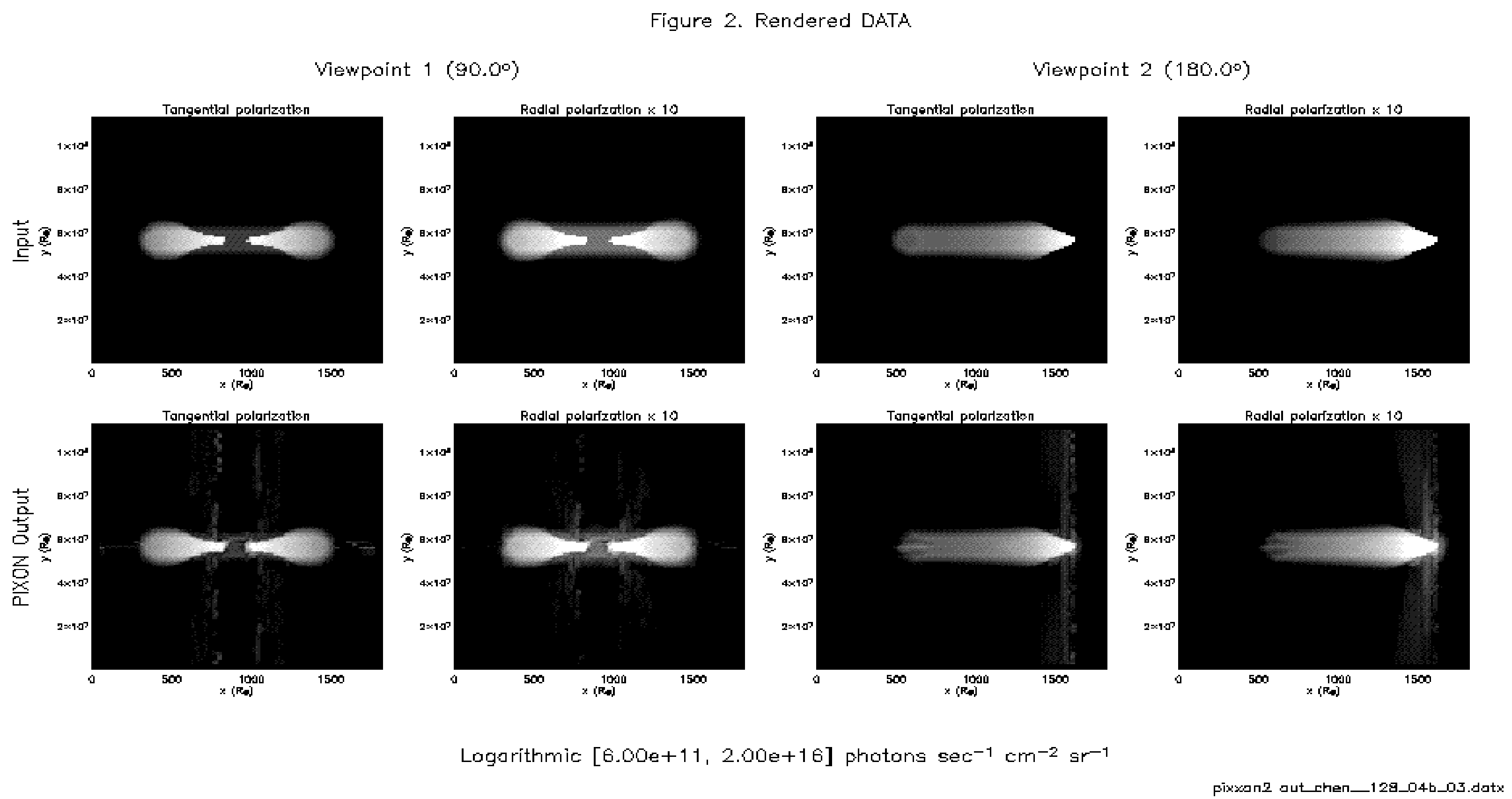
- **Strategy: Apply 3D tomographic electron density reconstruction techniques to solar features from low corona through heliosphere to 1 AU. Utilize Brightness, polarized brightness, temporal, 2D white light coronagraph images and synthetic models from 2/3 vantage points, construct (time dependent) 3D electron density distribution.**
- **Focus: Use theoretical CME models and existing LASCO observations prior to STEREO launch in order to predict the range of conditions and features where reconstruction techniques will be applicable.**
- **Goal: Provide a practical tool that will achieve ~daily CME 3D electron density models during the STEREO mission.**
- **Study realistic complexities: Input Synthetic Models -> density structures (uniform vs. cavity vs. "realistic"), K/F corona, time dependence**

# NRL 3D WL: Key Aspects

- **Renderer - Physics (Thomson scattering), tangential and radial polarization brightness, total brightness, finite viewer geometry, optically thin plasma.**
- **Reconstruction Algorithm - PIXON (Pixon LLC), Pina, Puetter, Yahil (1993, 1995) - based upon minimum complexity, non-parametric, locally adaptive, iterative image reconstruction. Roughly analogous to multiscale (wavelet) methods (not as closely related to maximum entropy).**
  - **chosen for speed (large # voxels, up to 10^9): small number of iterations, intelligent guidance to declining complexity per iteration. Sample times have been 32x32x32 <15 minutes, 64x64x64 ~60 minutes, 128x128x128~6 hrs, (1 GHz PC).**
  - **Minimum complexity: With this underdetermined problem, we make minimal assumptions in order to progress. Another possibility is forward modelling, i.e. parameter fitting. Complementary approach.**
- **Visualization - 3D electron density distribution, time dependent (movies), multiple instrument, multiple spacecraft, physics MHD models.**

# 3D Reconstruction: CME model (J. Chen)

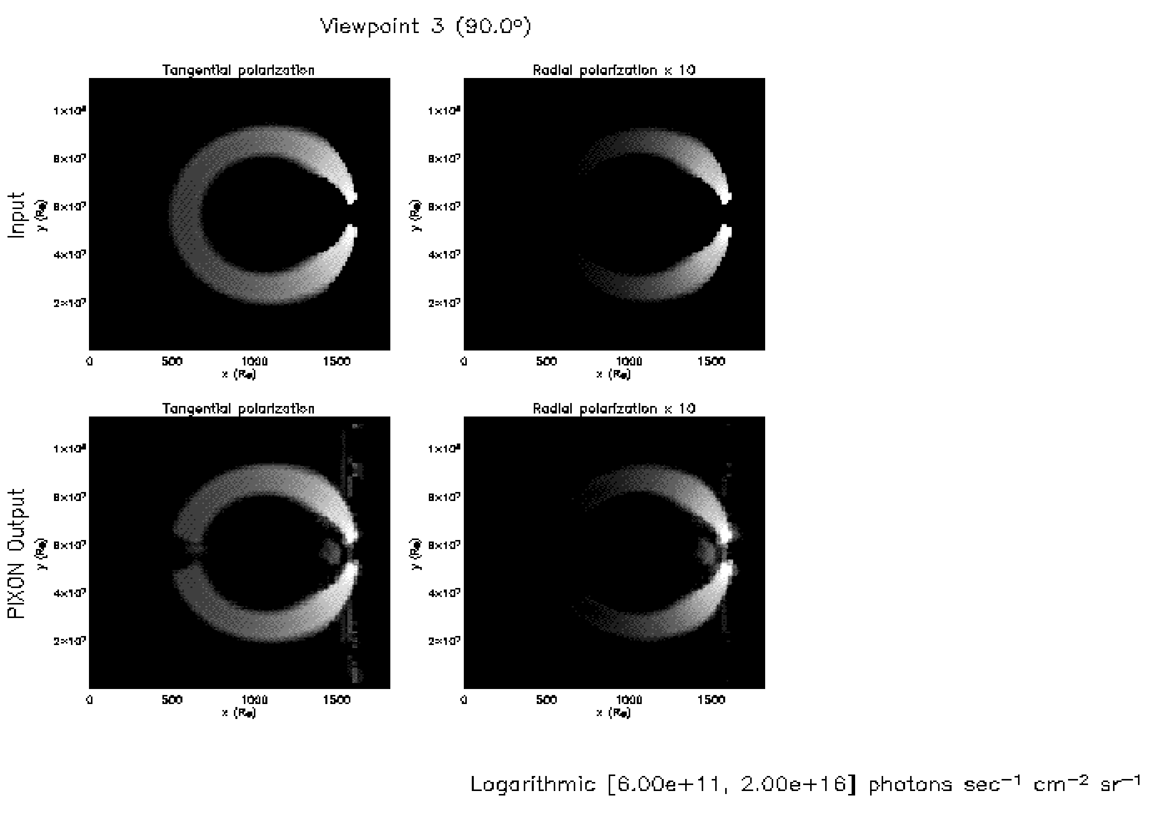
# Three Orthogonal Viewpoints:



# 3D Reconstruction: CME model (J. Chen)

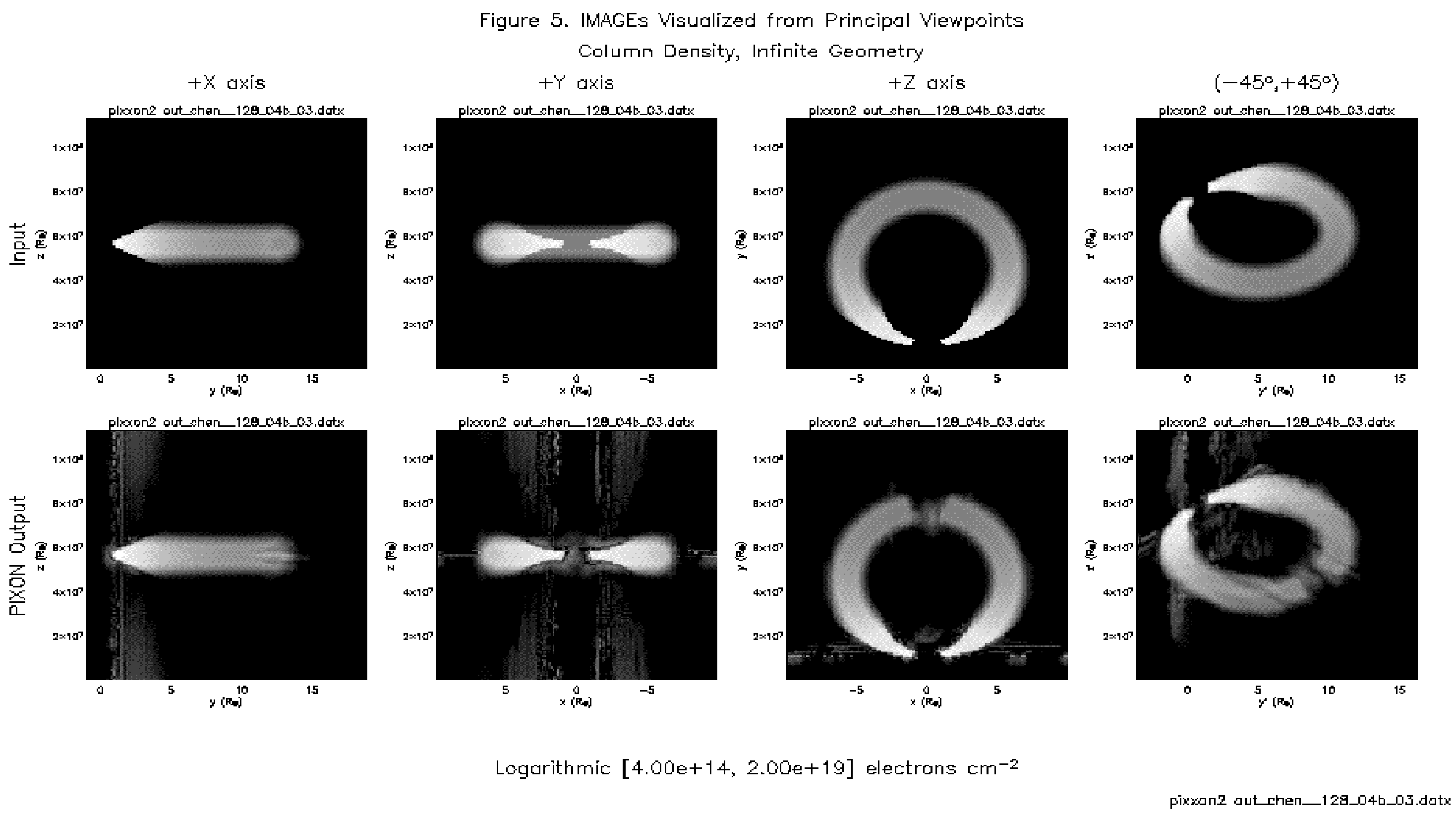
## Three Orthogonal Viewpoints:

Figure 2. Rendered DATA



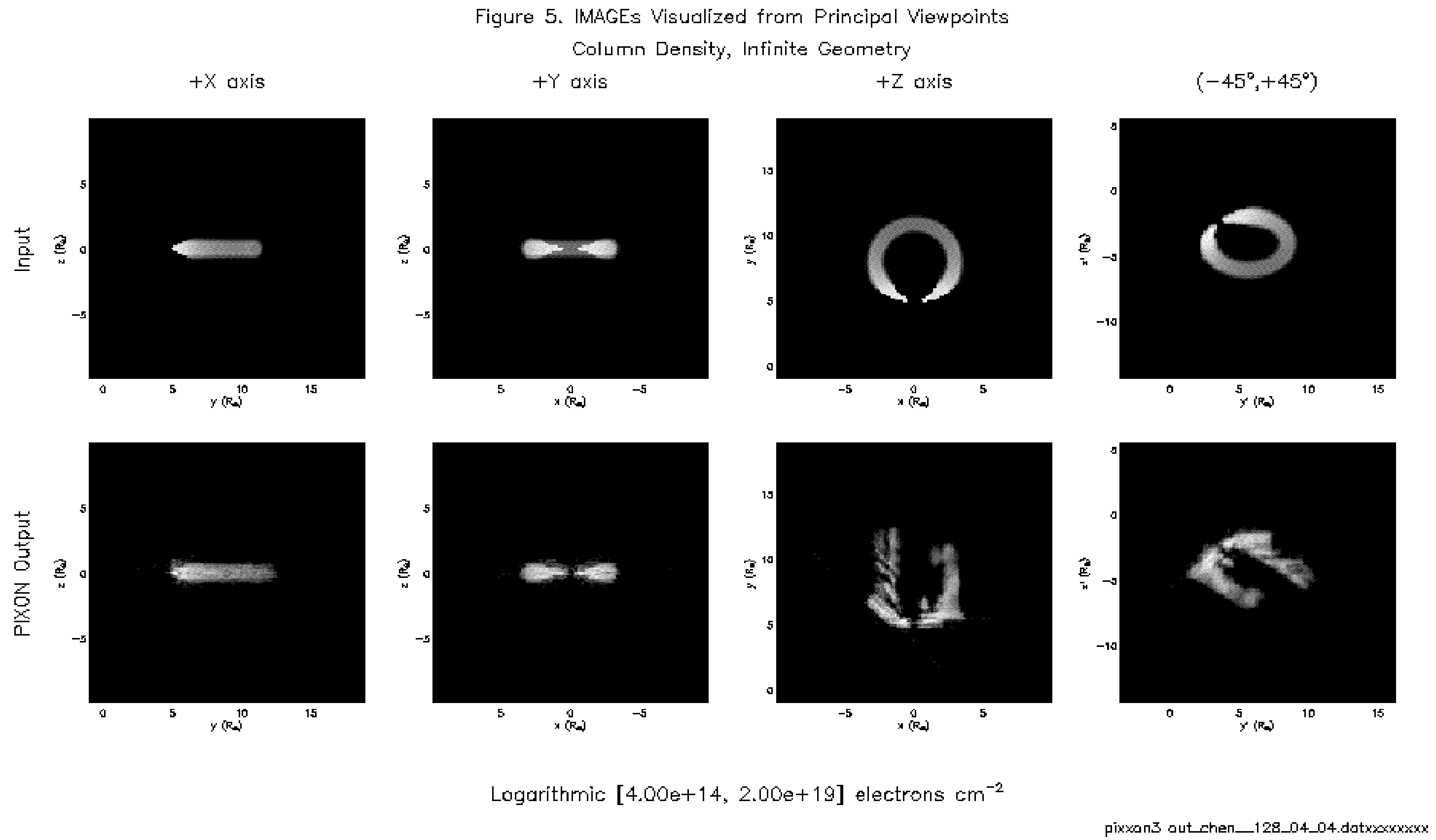
# 3D Reconstruction: CME model (J. Chen)

# Three Orthogonal Viewpoints:

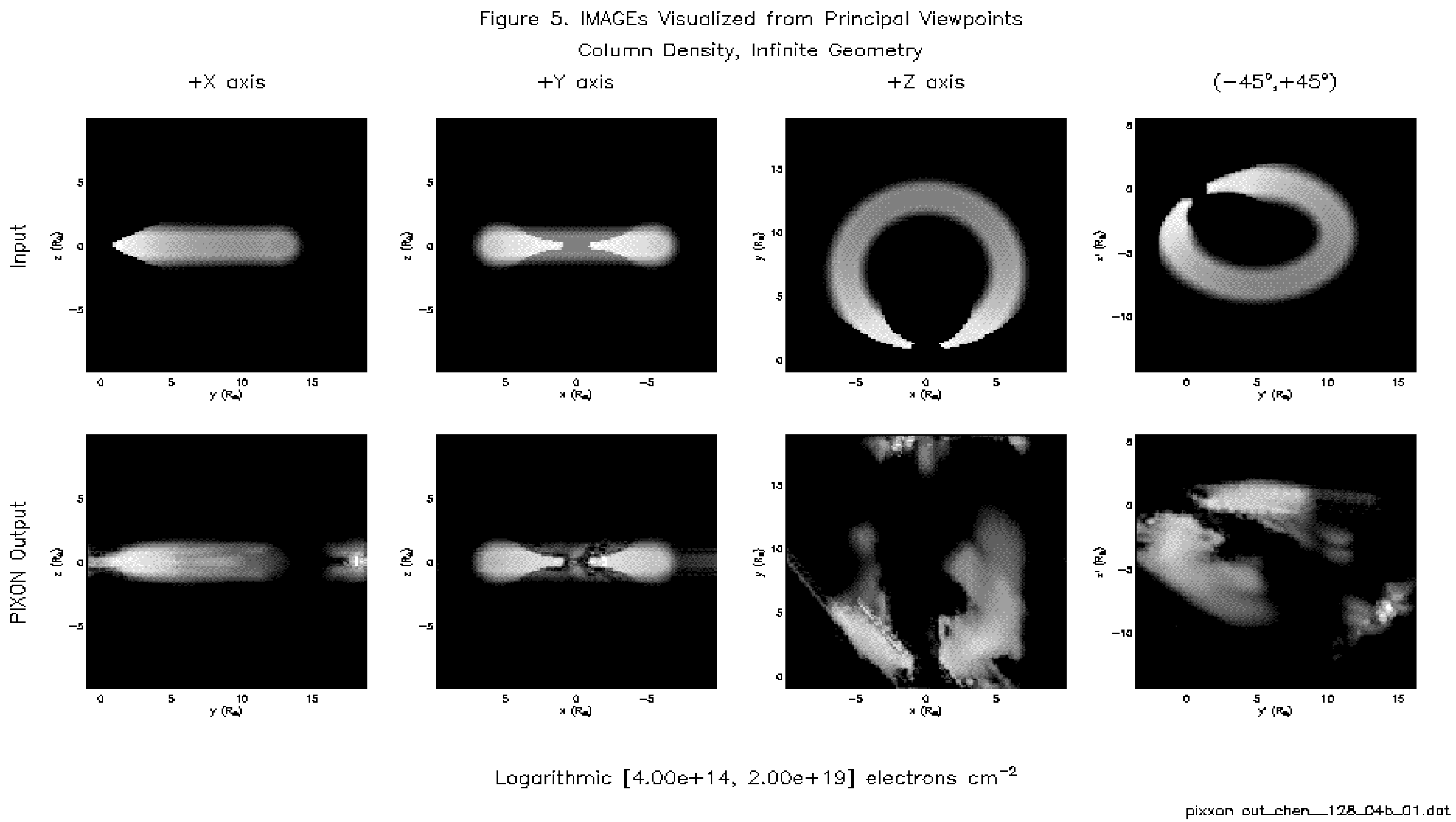


# 3D Reconstruction: CME model (J. Chen)

# Three Ecliptic Viewpoints: Image



# 3D Reconstruction: CME model (J. Chen)



# NRL 2: Determining the Ne for a CME

- **For a transient event, such as a CME, the problem of determining K is quite straightforward, since we are only interested in the excess mass.**
- **In this case we use a pre-event image to subtract the entire background from the image that contains the event.**
- **Knowing the electron density, a simple conversion calculates the mass**

- **Note:  calculating the total excess mass only counts mass that comes up from below the occulting disk – it does not consider mass that has been transported from lower to higher heights, all within the field of view of that coronagraph**

- **This procedure has been automated, and only needs to know the times of the event, the radial height of the leading edge, the central latitude or position angle and the angular span.  Vourlidas et al 2003 has derived the following plot of the results of calculating the mass of over 4000 LASCO CMES**

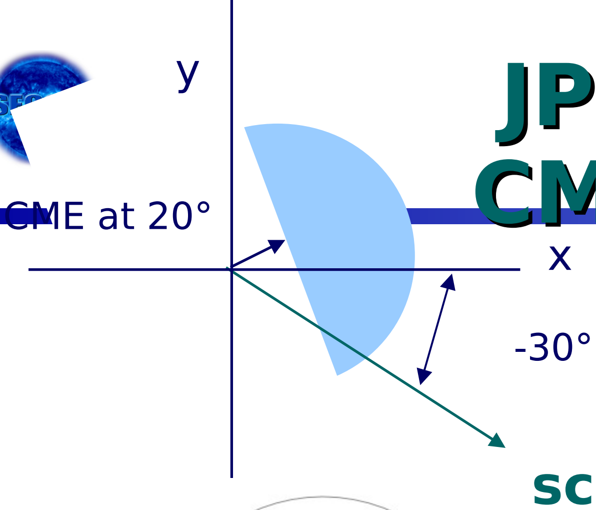
# NRL 2: Determining Ne for a Coronal Structure

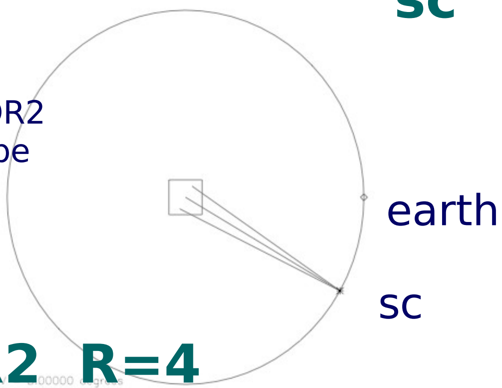
- To calculate the electron density in a non-transient structure requires a different technique.
- We have developed two different approaches, one using polarized brightness observations and the other using total brightness observations. The software for both of these approaches is available in the LASCO software tree.
- In both techniques, a radial cut through the pB or Bt corona, at a particular position angle, is obtained and then fit to a polynomial. Using an assumption of spherical symmetry, we then can then perform the inversion.
- The pB technique was developed by van de Hulst in the 1950s and has been used for many years by many groups. It depends on the assumption that pB = K, ie that all the other sources contributing to the observations are not polarized. This is usually not a bad assumption inside of about 3-4 solar radii.
- The Bt technique was developed by Hayes et al (2001). It depends on knowledge of each of the contributions given earlier.

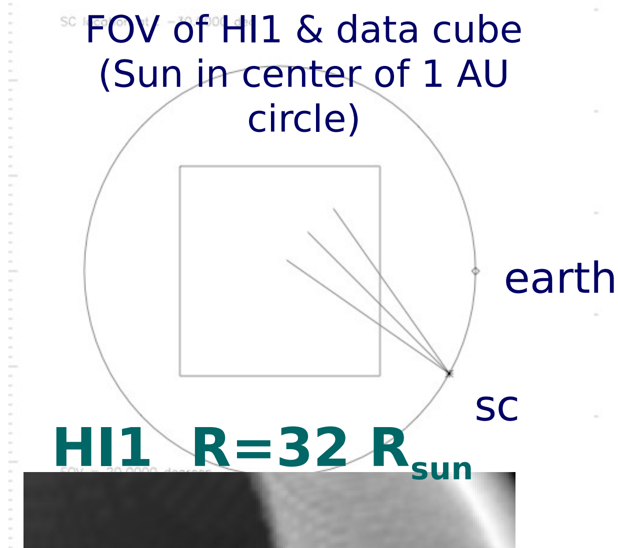
# NRL 2: Forward Modeling

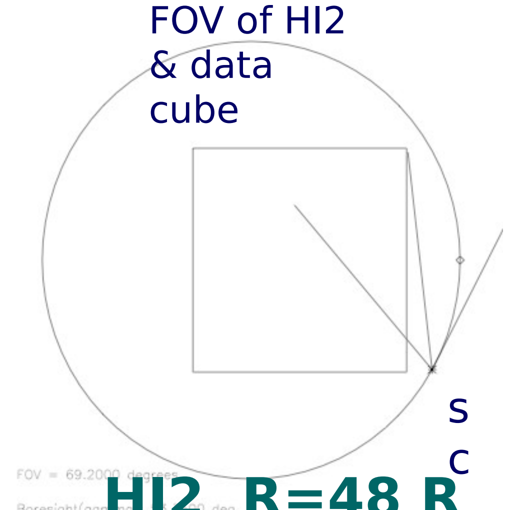
- **Another technique we have started on is to assume a structure and then empirically generate a good fit to the observations. The difficultly with this approach is that the structure is only as good as your imagination and that many different structures may be equally suitable (or unsuitable)**
- **This procedure allows you to specify the location in solar coordinates of a structure or combination of structures that are present in the corona and then allows you to view the resulting brightness image that would be generated from any angle. The structures must be expressed analytically.**
- **We currently have various structures defined to represent possible streamer structures (slabs with a gaussian density, constant density cross section or gaussian-ellipsoid cross sections; a warped current sheet), a coronal hole.**
- **We will be adding structures of possible CME representations – cone, spherical shell, ellipsoidal shell are currently envisioned.**
- **We will also be making it more “user-friendly”.**

# JPL: SynLOS - Hemisphere CME at 20° viewed from SC at -30°

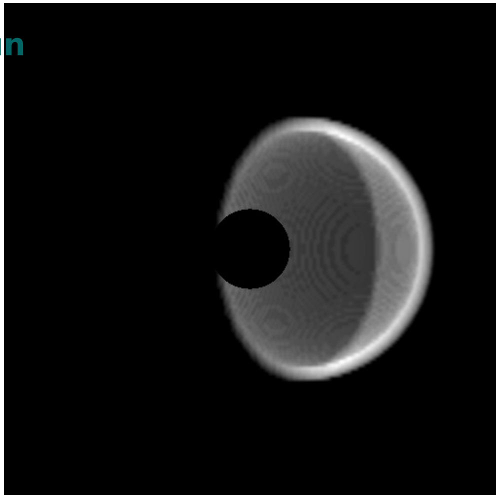


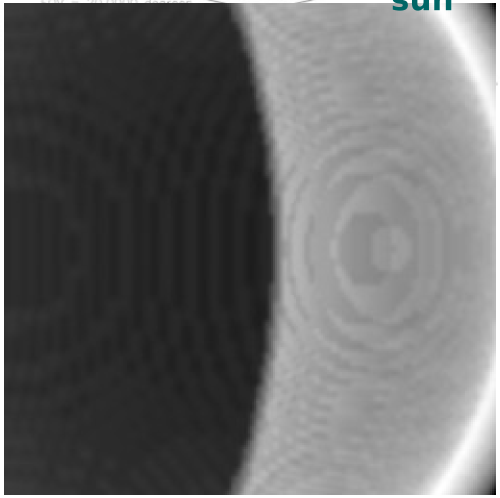



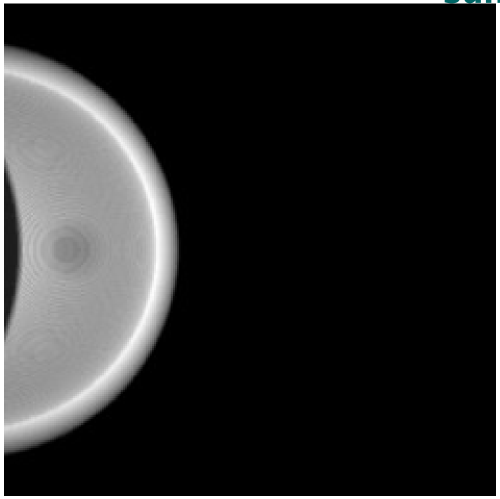

**COR2 R=4 $R_{sun}$**



**HI1 R=32 $R_{sun}$**



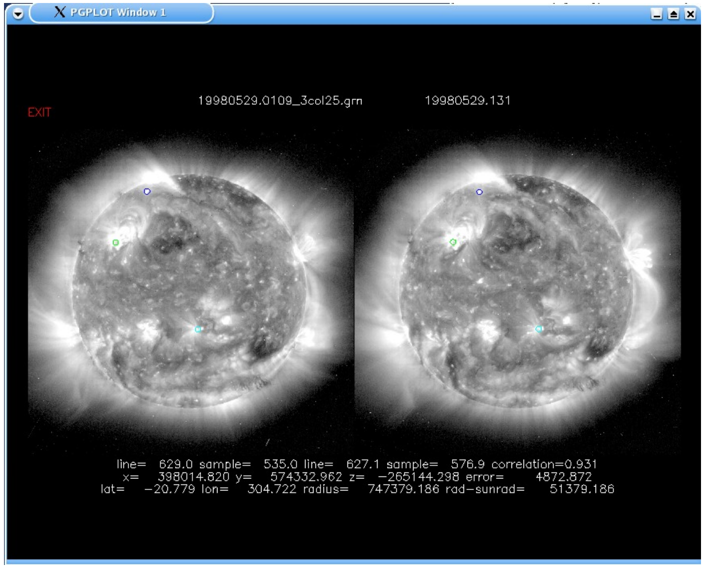
**HI2 R=48 $R_{sun}$**



# JPL: Stereoscopy: Tie Point Tool

*Classical Stereoscopy: Determine 3D location of a “Feature” identified in both images of a stereo pair using triangulation*

- **Minimum platform-independent tool (Now Exists):**
  - **Manual placement of tie points in displayed stereo image pair**
  - **Computation of 3D location of feature in heliographic coordinate system *(uses program xyzsun)***




Can be used to trace out loops (EUVI) and to compute 3D velocities of features from time series of stereo images, e.g., CME velocities (CORs and HIs)

# LMSAL: Forward-fit Algorithm for Stereo I

1. Selection of structure-rich multi-wavelength image from TRACE, EIT, and/or Yohkoh database (with filament, flare, CME, fluxropes, etc.)
2. Tracing linear features (loops, filaments, fluxropes) in 2D: s(x,y)
3. Inflation from 2D to 3D with prescription z(x,y) s(x,y) -> s(x,y,z)
4. Physical model of structures: T(s), n(s), p(s), EM(s)
5. Geometric rotation to different stereo angles EM(x,y,z) -> EM(x',y',z')
6. Line-of-sight integration EM(x',y')=∫EM(x',y',z')dz' and convolution with instrumental response function

→ http://www.lmsal.com/~aschwand/ppt/2002_Paris_ster

# LMSAL: 3D Geometry [x(s),y(s),z(s)] of coronal coronal structures, such a filaments, loops, arcades, flares, CM

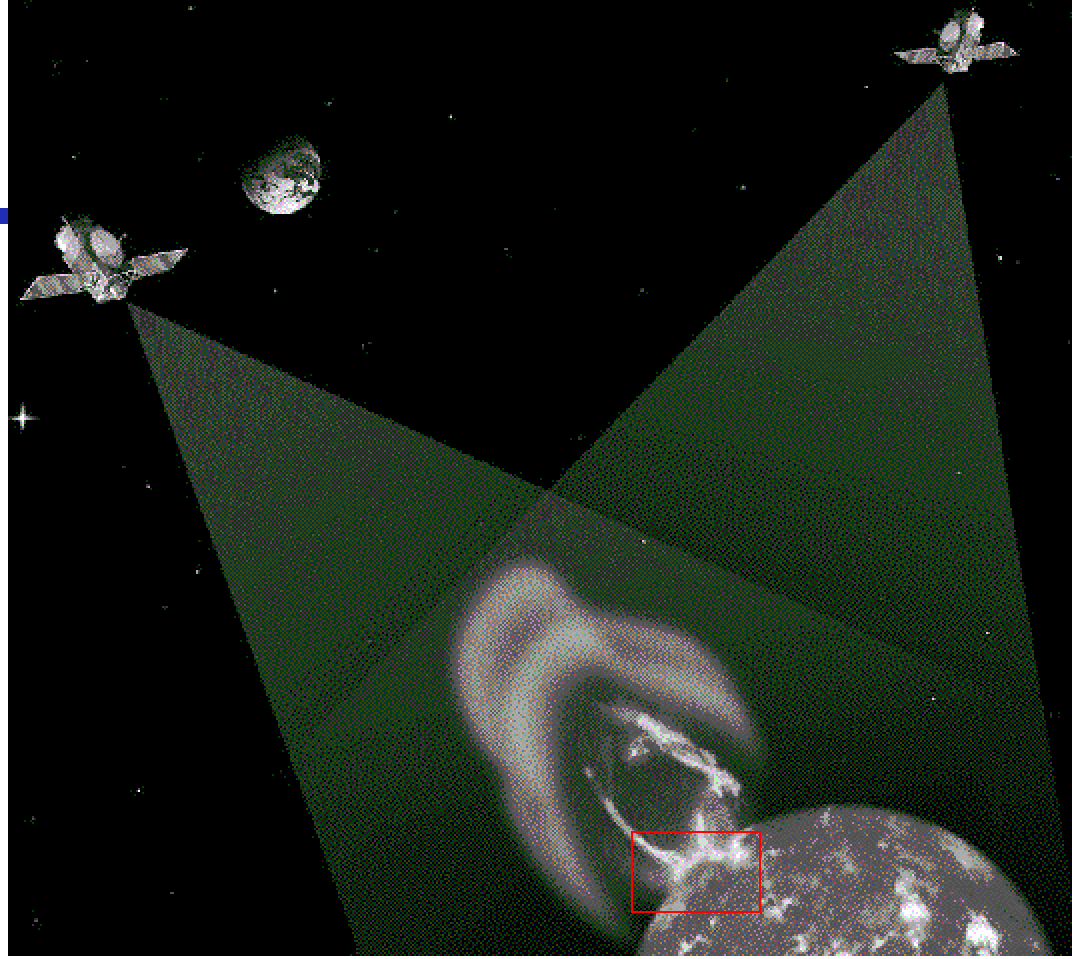
- **Geometric definitions :**
  **1-dim parametrization along magnetic field lines is in low-beta plasma justified --> [x(s),y(s),z(s)]**

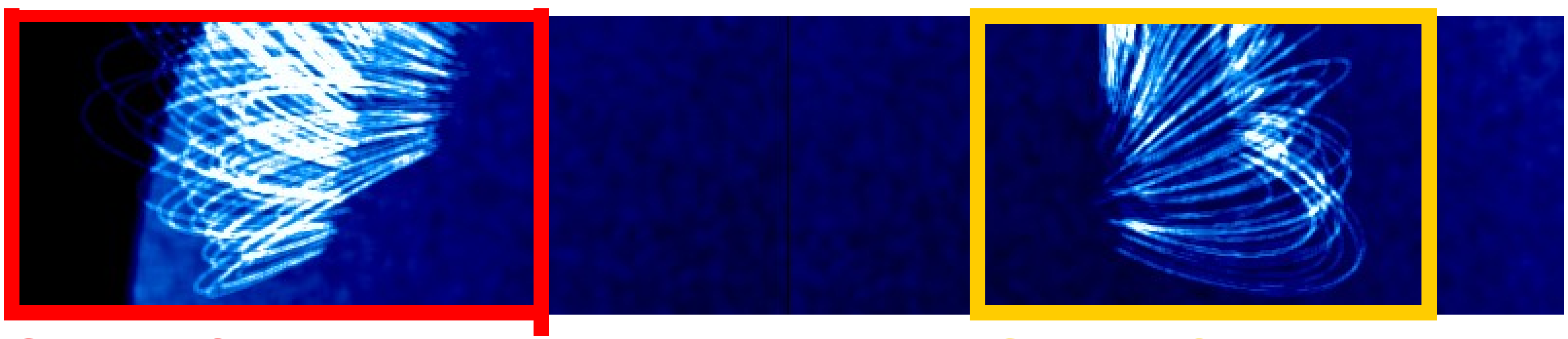
- **Cross-sectionial variation for loops, --> A(s)**

- **Start with tracing in 2D in first STEREO image --> [x(**

- **Model for 3D inflation z(s),**
  **e.g. semi-circular loops with vertical stretching facto**
  **z(s)=sqrt[(x(s)^2 + y(s)^2]*q_stretch**

- **Forward-fitting to second STEREO image to determin**

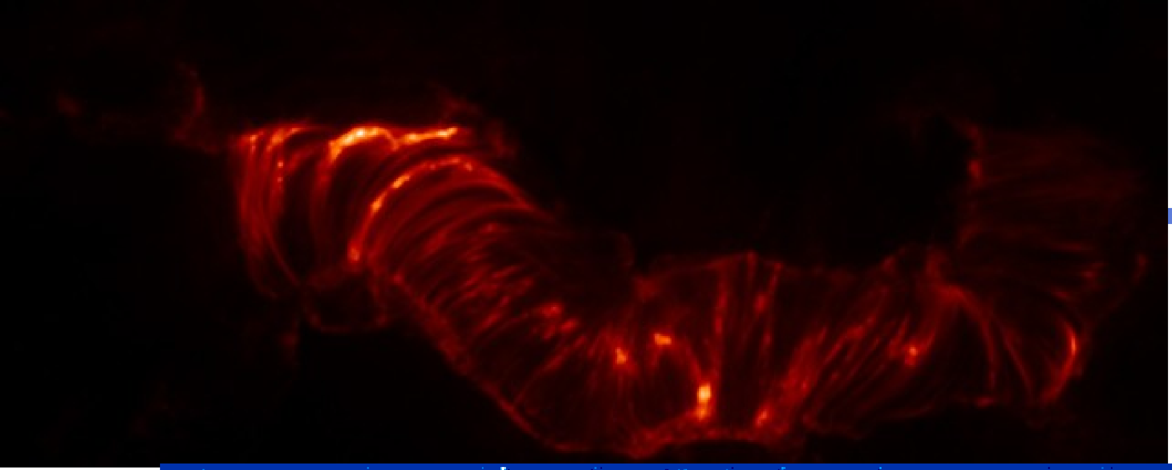


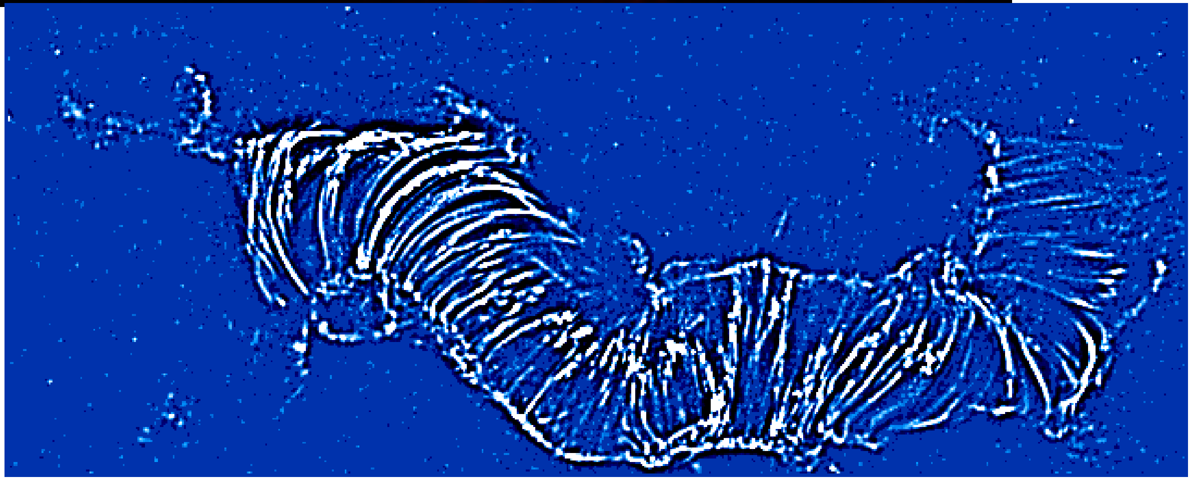


STEREO - A

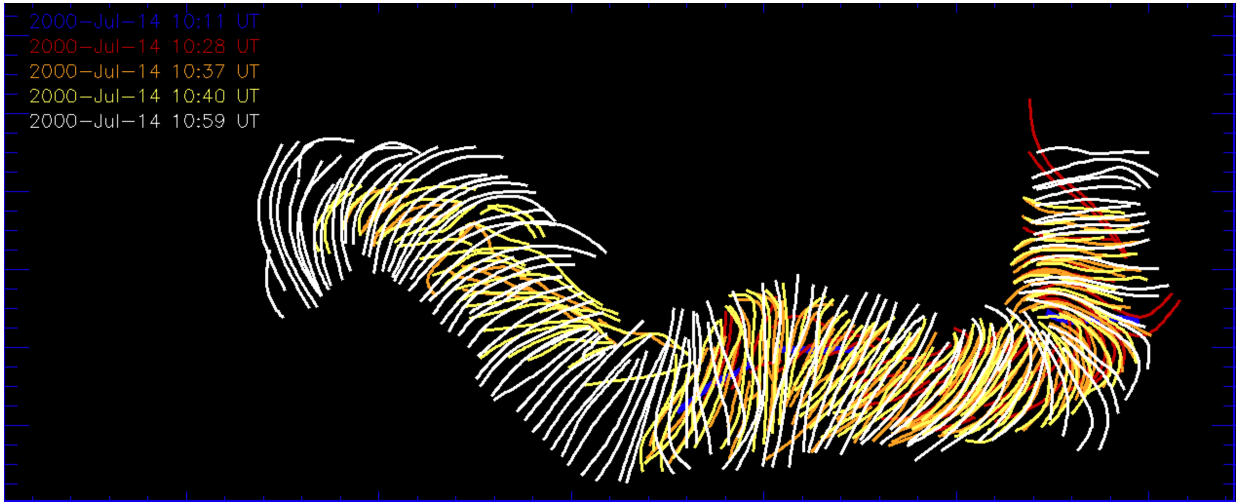
STEREO - B

# LMSAL: Tracing linear features : --> [x(s),y(s)]





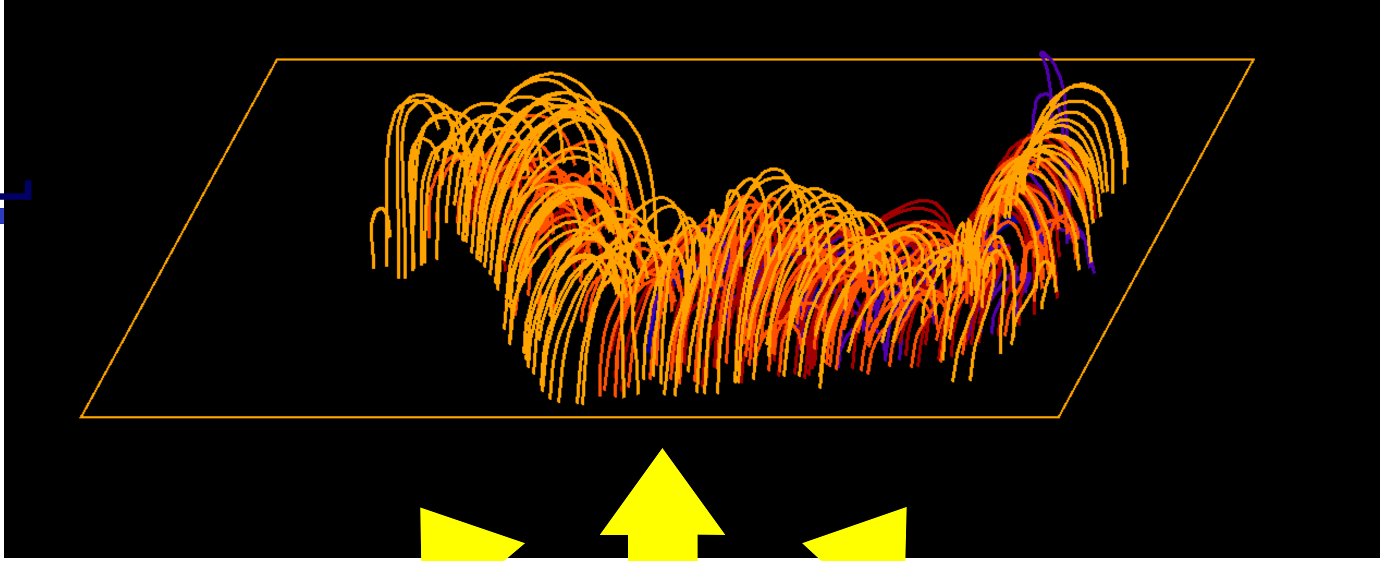
High-pass filtering




Feature tracing, reading coordin spline interpolat

# LMSAL

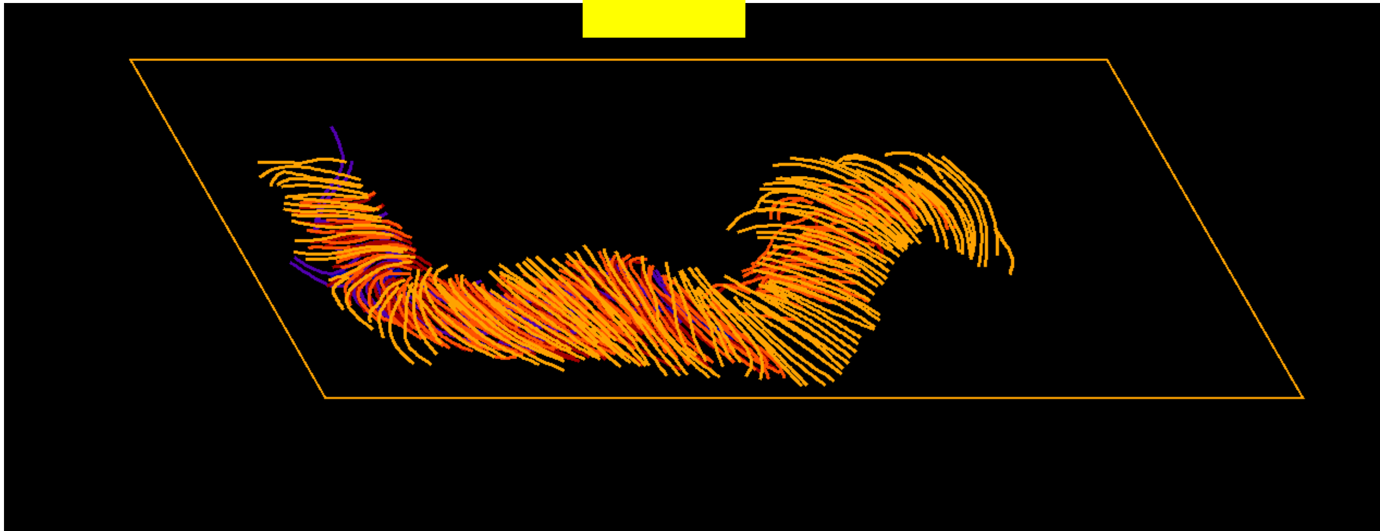
# s(x,y,z)



Step 3:

3D Inflation:  z=0 -> z(x,y)

- model (e.g. semi-circular loops)
- magnetic field extrapolation
- curvature minimization in 3D



# s(x,y)

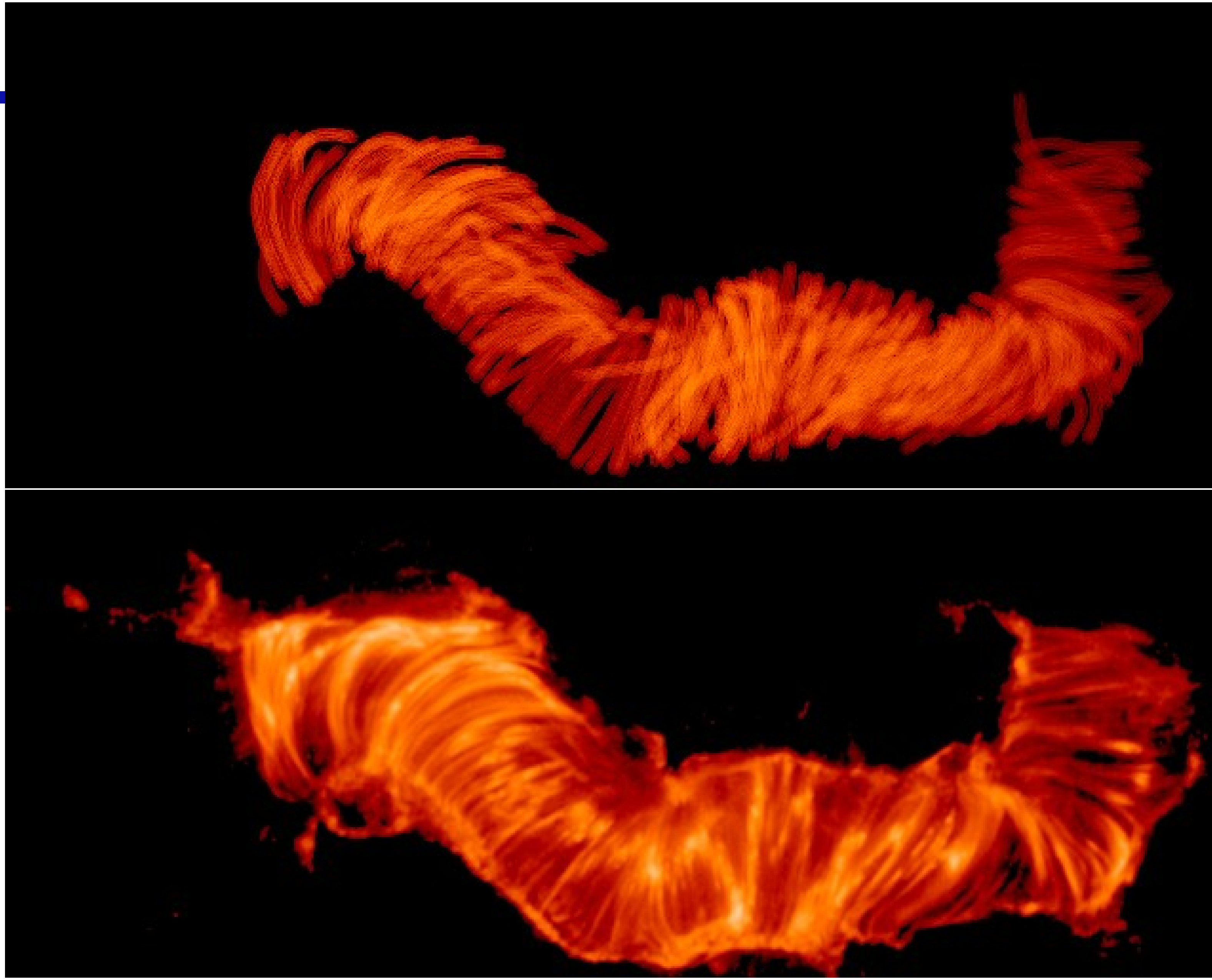
# * LMSAL: 3D Fitting: F[x(s),y(s),z(s)] Volume rendering of coronal structu

- **Flux fitting in STEREO image**
  - **Volume filling of flux tube with sub-pixel sampling**
  - **Render cross-sections by superposition of loop fibers with sub-pixel**
  - **cross-sections: A=Sum(A_fiber), with w_fiber<pixel**

  - **Loop length parametrization with sub-pixel steps ds<pixel**

  - **Flux per pixel sampled from sub-pixel voxels of loop fibers**

# LMSAL: Forward-Fitting of Arcade Model with 200 Dynamic Loo





Observations from TRACE 171 A : Bastille-Day flare 2000-July-1

# * LMSAL: 4D Fitting: F[x(s),y(s),z(s),t] of coronal coronal structures

- Flux fitting in STEREO image #1 at time t1 :

$$F(x,y,t=t_1)_{obs} \Rightarrow F[x(s),y(s),z(s),t=t_1]_{model}$$

- Flux fitting in STEREO image #2 at time t1

- Sequential fitting of images #1,2 at times t = t2, t3, .... , tn

# LMSAL: 5D Model: DEM [x(s),y(s),z(s),T(s),t] with dynamic physical model

Ingredients for flare loop model :

- 3D Geometry [x(s), y(s), z(s)]
- Dynamic evolution [x(s), y(s), z(s), t]
- Heating function E_heat(s)
- Thermal conduction -∇F_cond(s)
- Radiative loss E_rad(s) = -n_e(s)^2 Λ[T(s)]

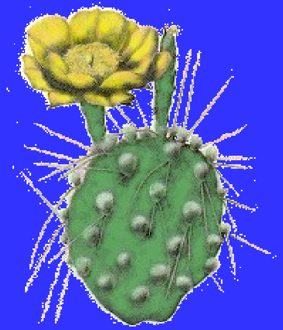
-> Differential emission measure distribution dEM(T,t)/dT

-> Line-of-sight integration EM(T)=∫ n_e(z,T,t)^2 dz (STEREO angle)

-> Instrumental response function R(T)

-> Observed flux F(x,y,t)= ∫ EM(T,t) * R(T) dT

-> Flux fitting of 5D-model onto 3D flux F(x,y,t)
for two stereo angles (4D) and multiple temperature filters (5D)



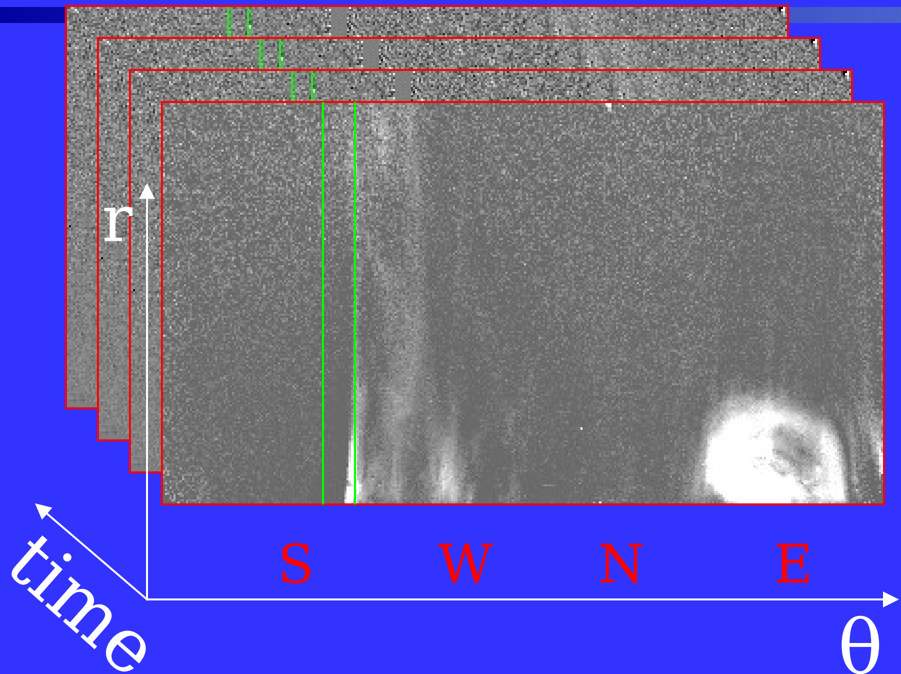
# CACTus

## Computer Aided CME Tracking


Eva Robbrecht
David Berghmans
Gareth Lawrence

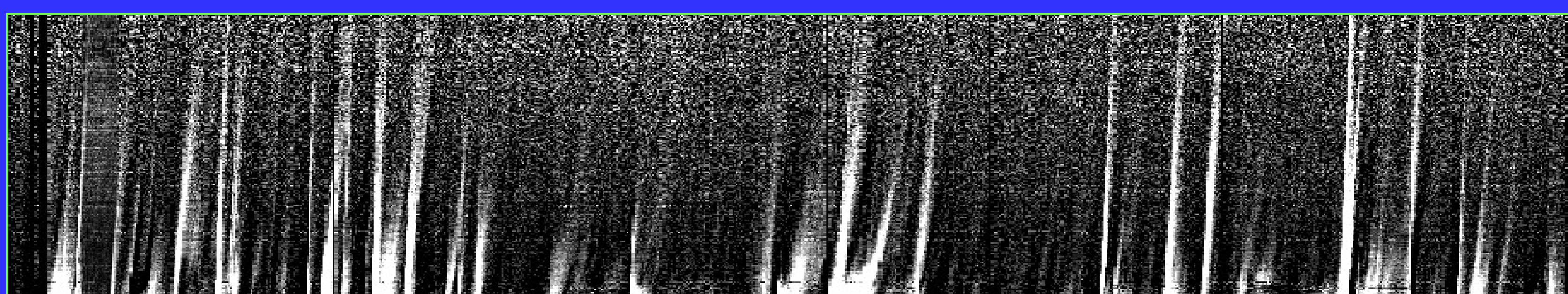
Royal Observatory of Belgium


# The catalyst



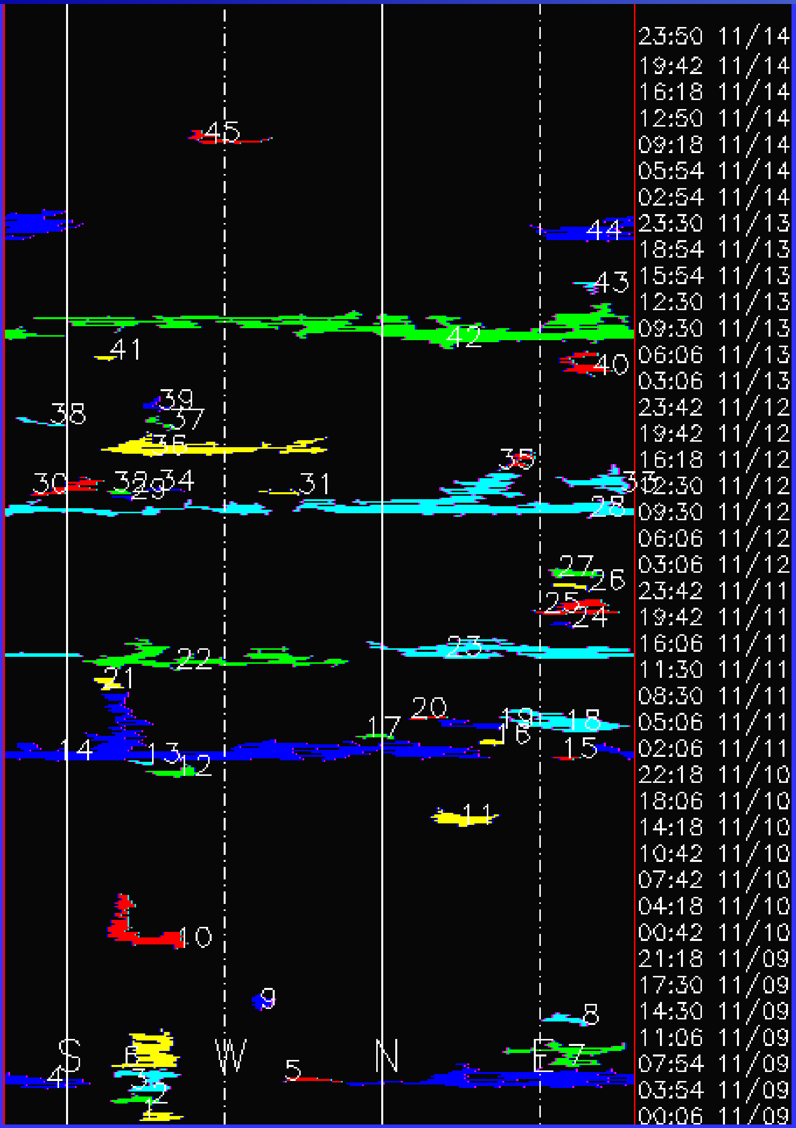

distance
from Sun

distance
from Sun

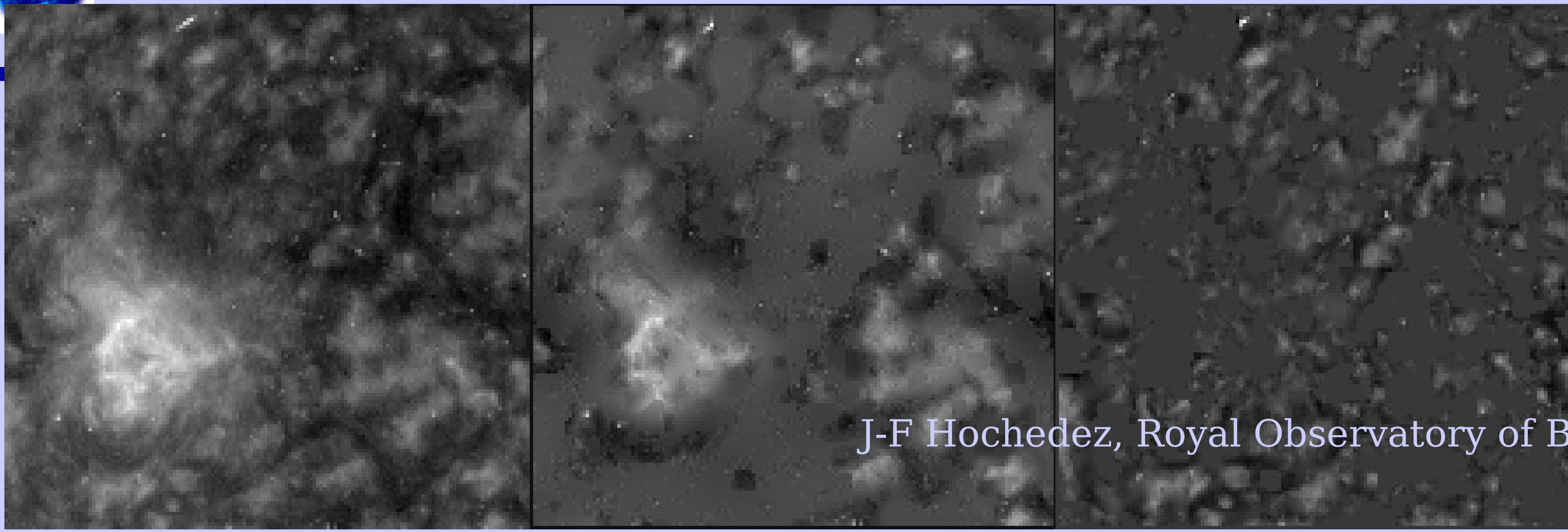


time

# ROB: Sample Output (test data Nov '03)



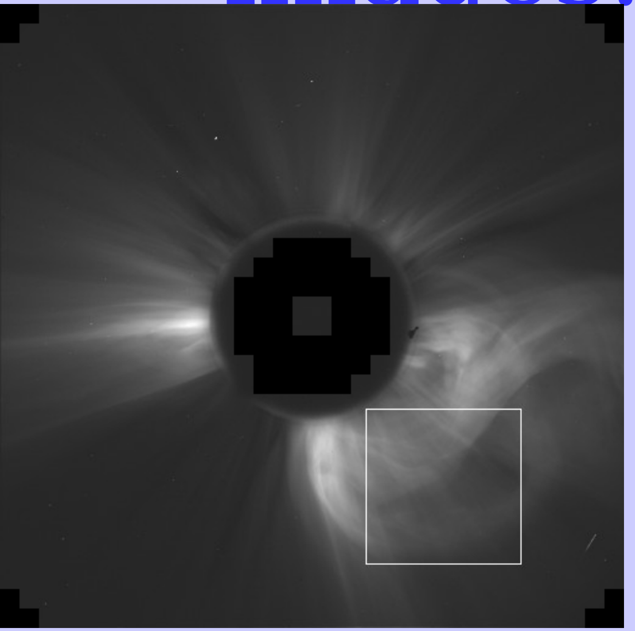
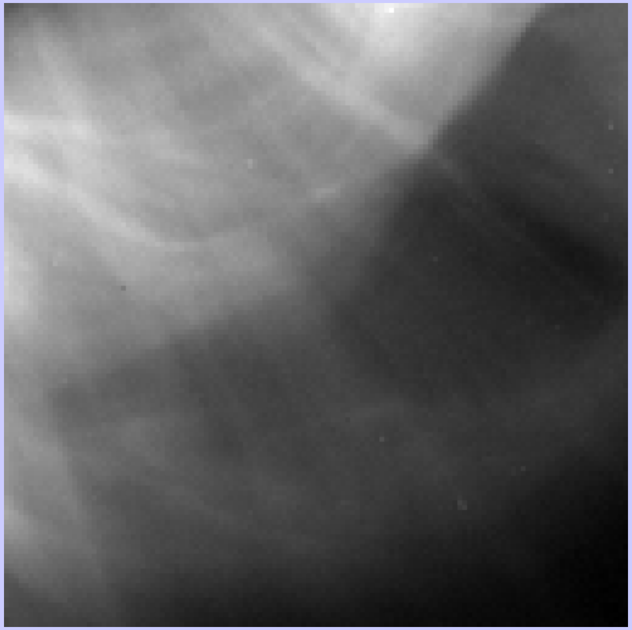
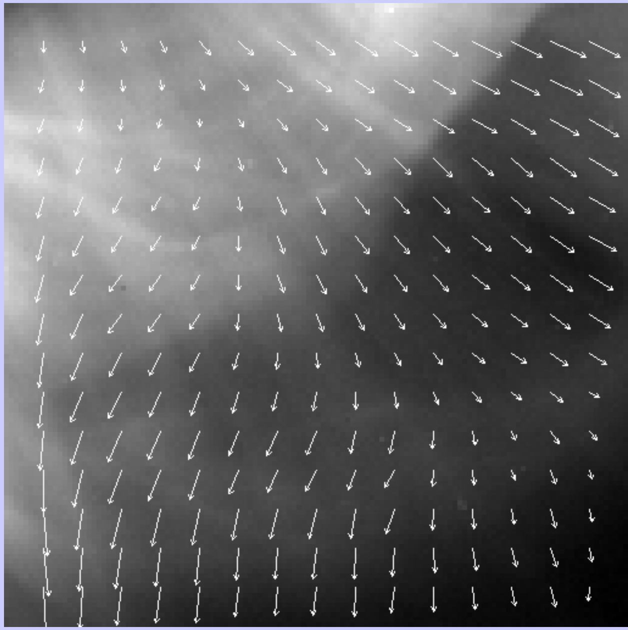
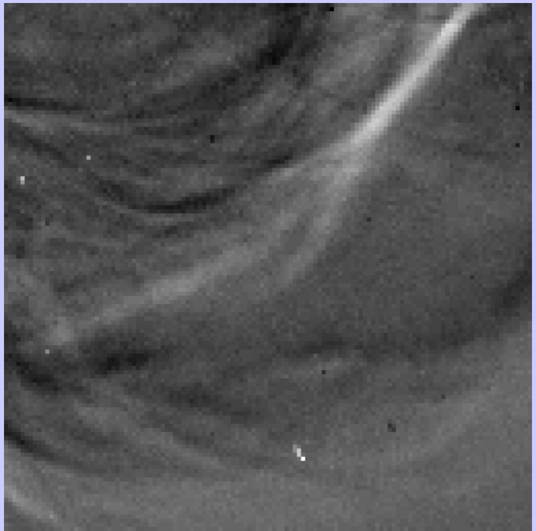
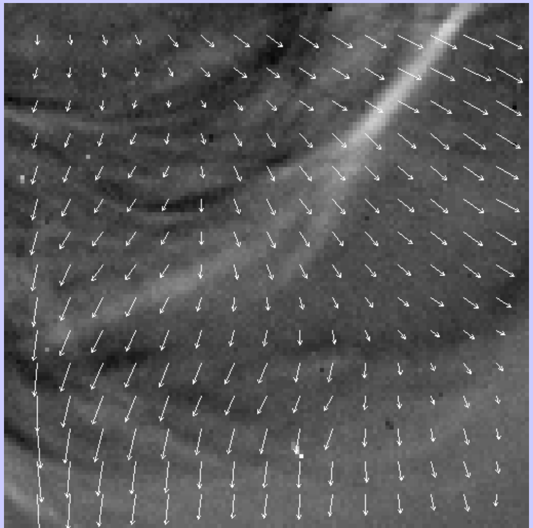
# ROB



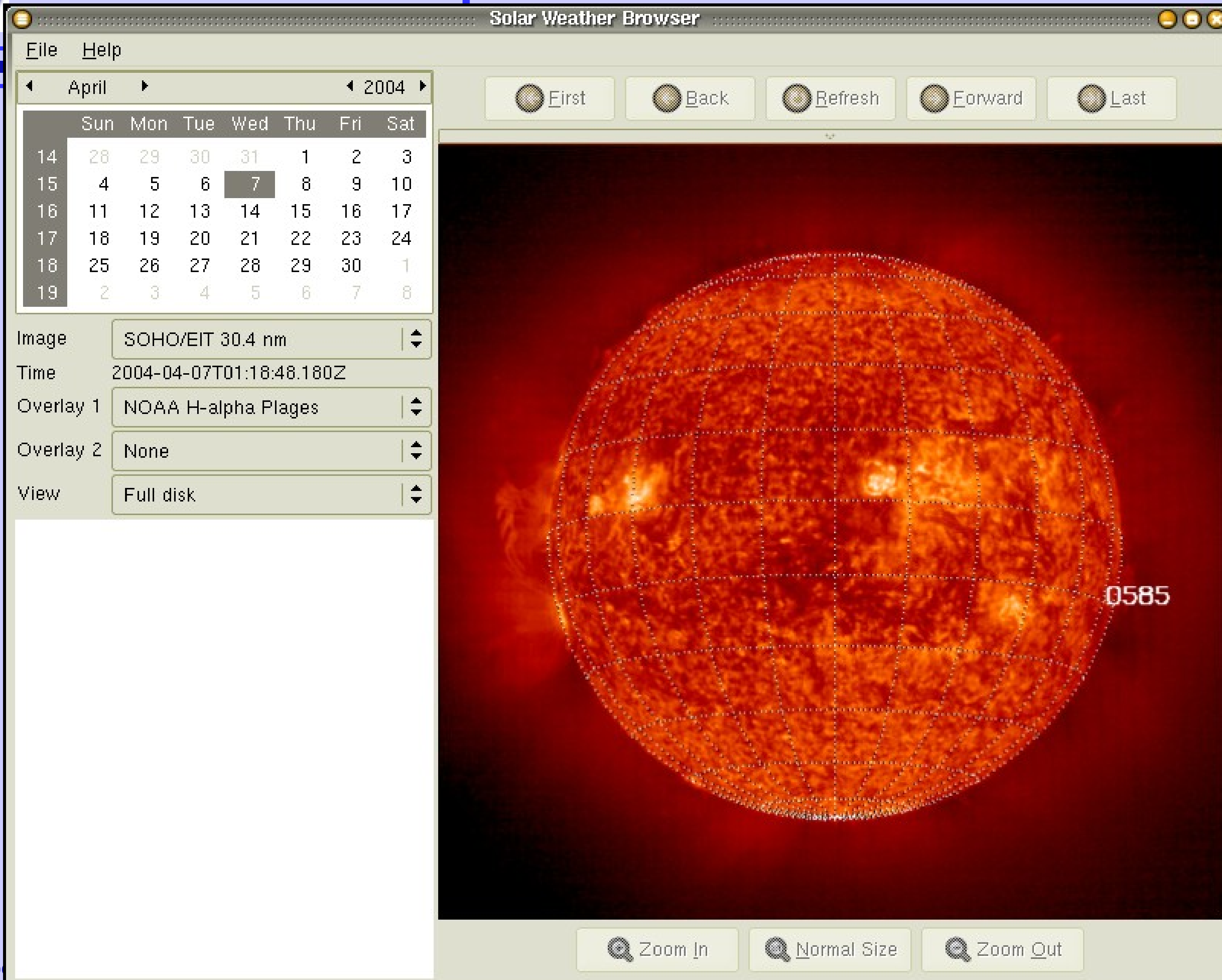

EIT 304, Shutterless June 2003

- Example of a EUV solar images decom
  - Wavelet transform & segmentation
  - Classification based on object parameters
- Possibility of tracking objects
- Application to SECCHI: tiepoints

# ROB: Sample LASCO images:

# ROB: Developmental Solar Data B:



# MPS: Magnetic fields tools

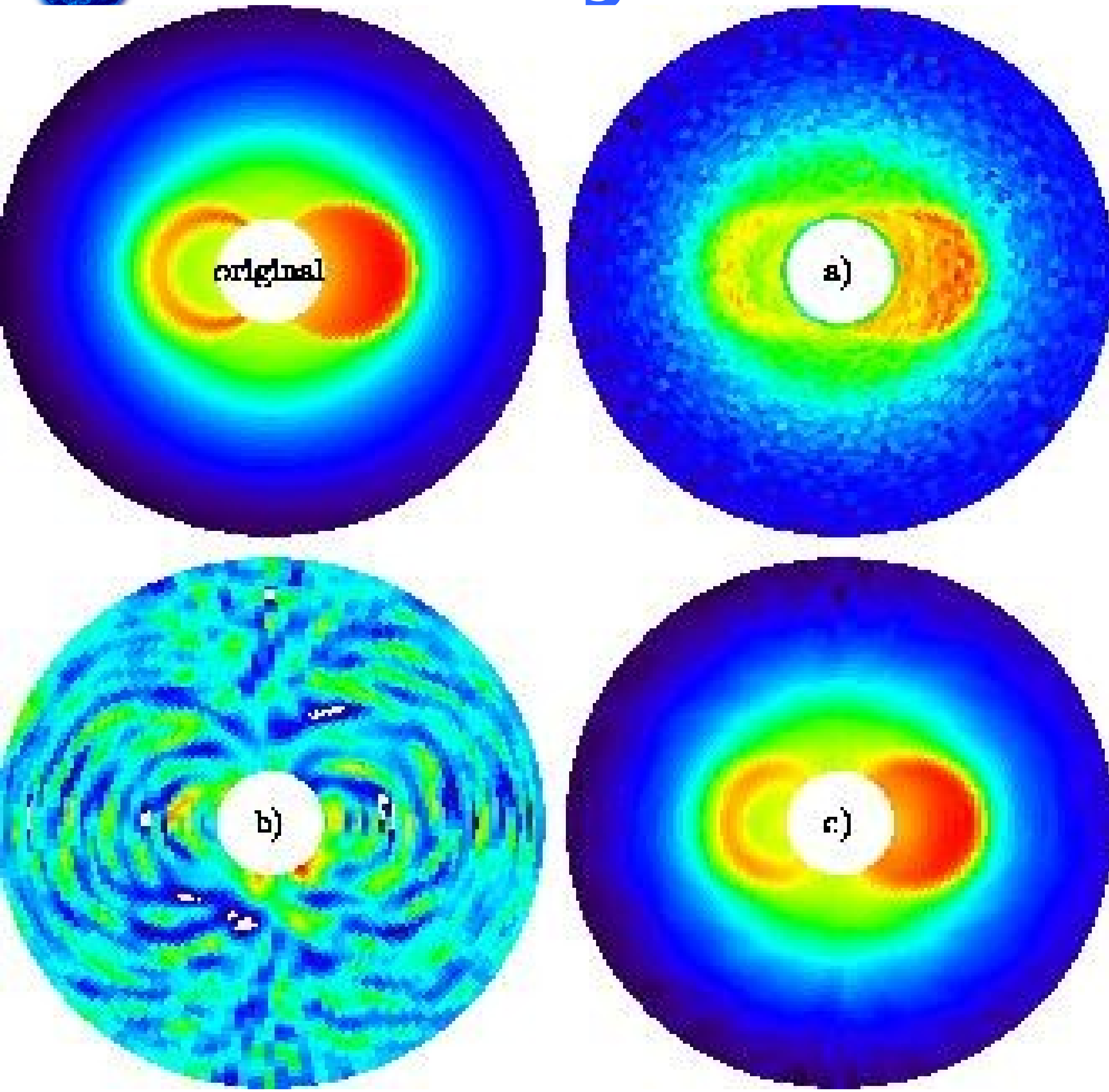
**Thomas Wiegelmann and Bernd Inhester**

Max-Planck-Institut für Sonnensystemforschung

**STEREO/SECCHI has no magnetograph.**
**Why do we develop magnetic field tools then?**

- **Magnetic field dominates and structures the solar corona (magnetic pressure >> plasma pressure)**
- **Coronal magnetic field is useful/necessary for Tomography and Stereoscopy.**
- **Photospheric magnetic field data are (will be) available e.g. from Kitt Peak, SOHO/MDI (SOLIS, Solar-B)**

# MPS: Magnetic fields and coronal

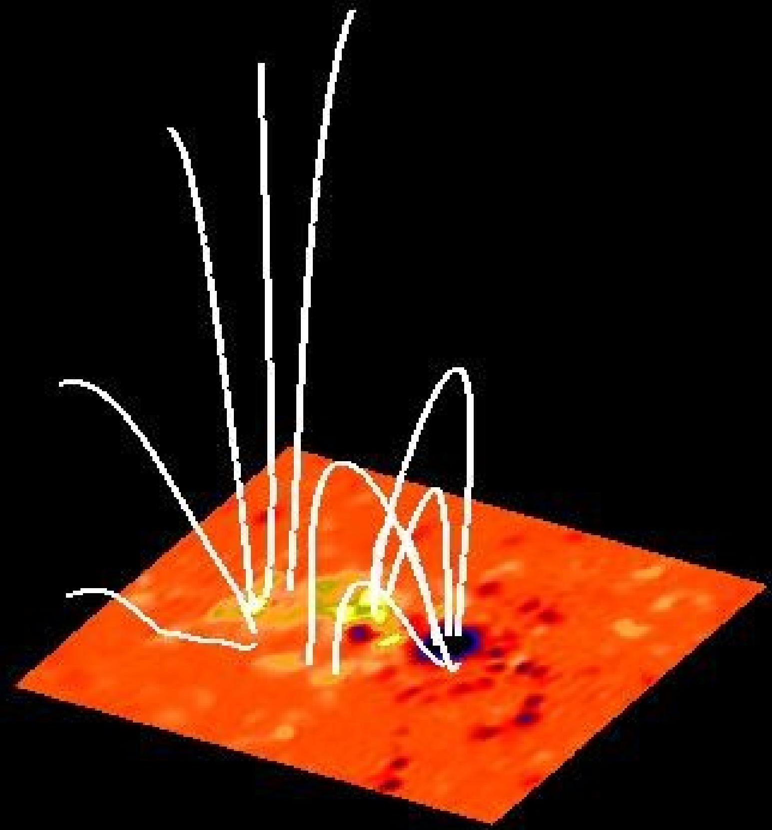


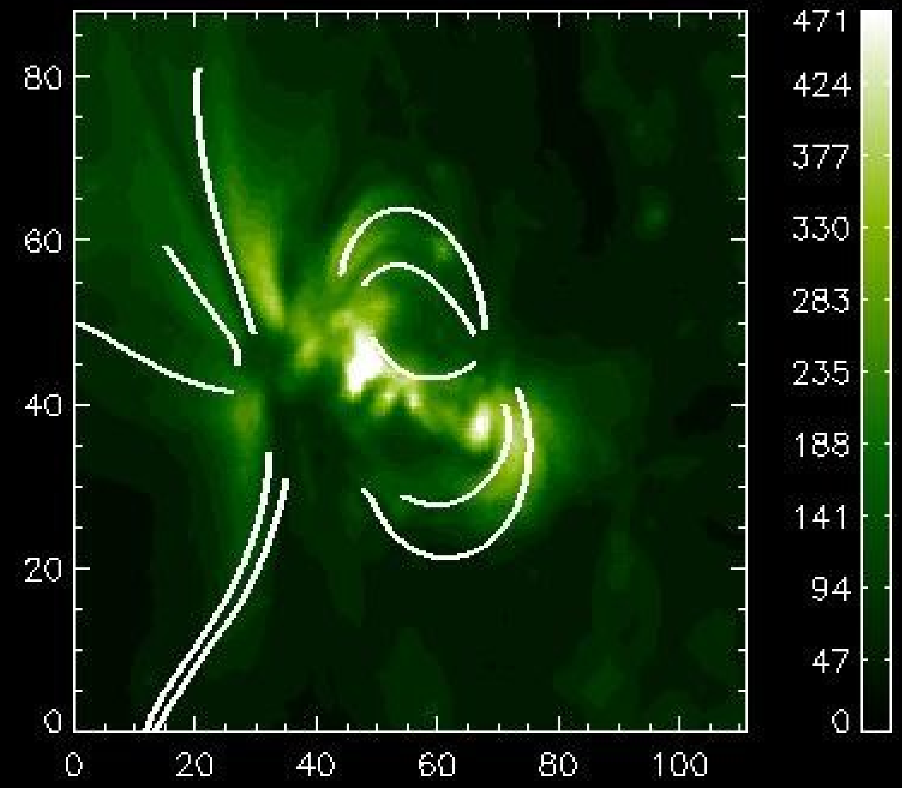

a) Use only line of sight density integ

b) Use only magnetic field data.

c) Use both line of si density integrals a magnetic field as regularization operator.

# MPS: Magnetic field outlines the coronal plasma

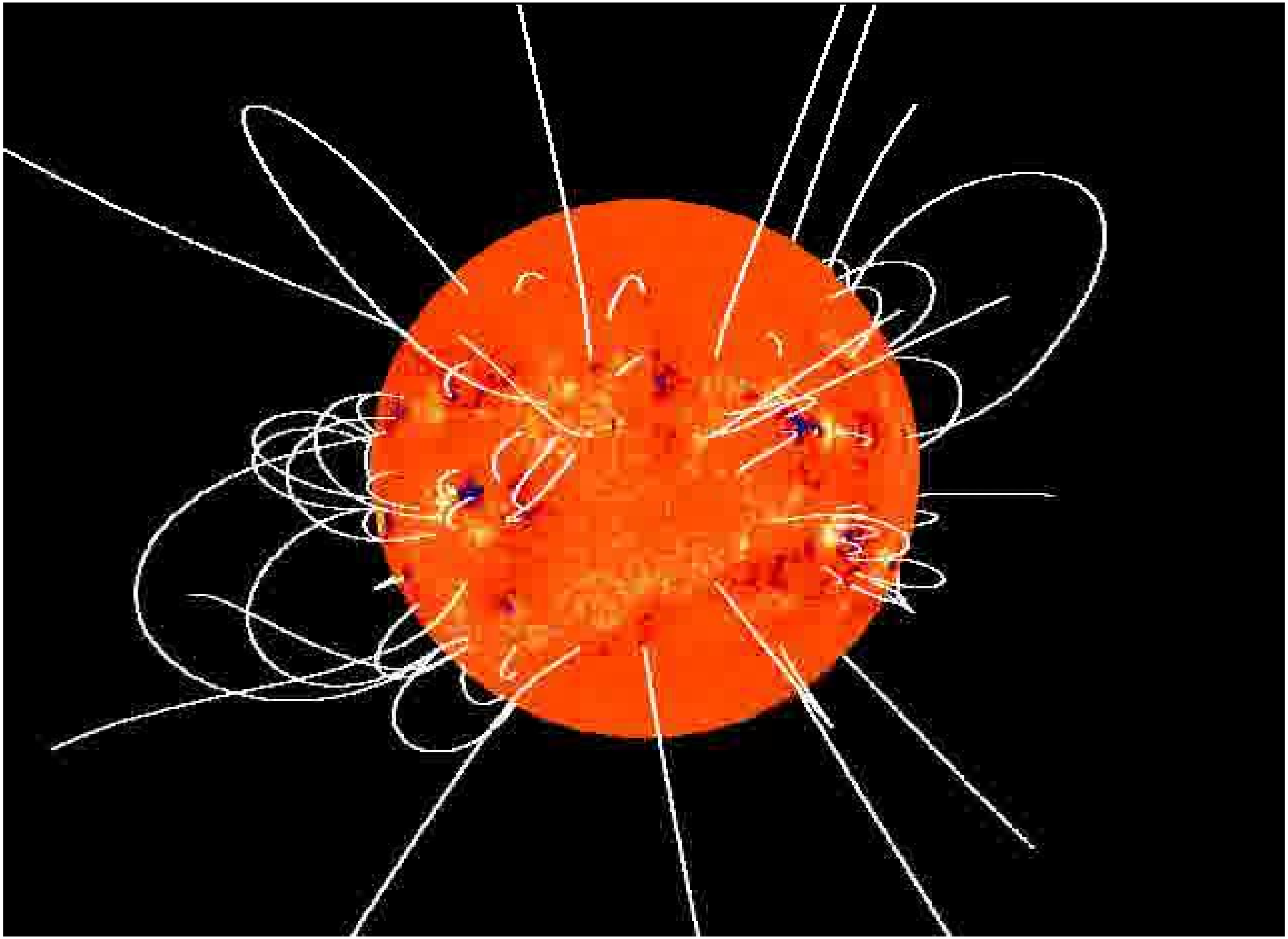





3D magnetic field lines, linear force-free field with $\alpha \cdot L=2$

EIT-image and projected magnetic field lines. Planed is (for SECCHI) to project the magnetic field on both

# MPS: Global Potential Field recons



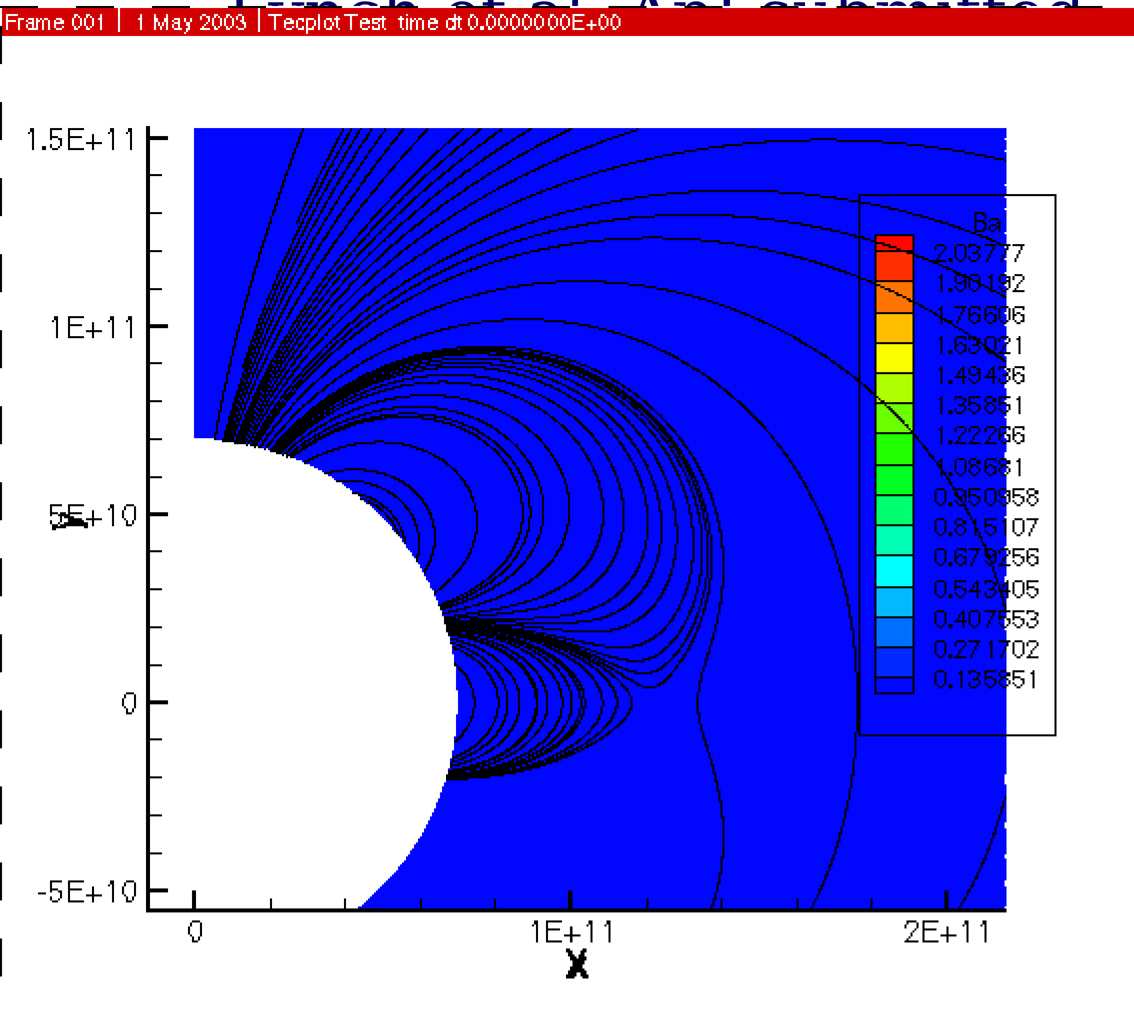
# MPS: Summary magnetic fields

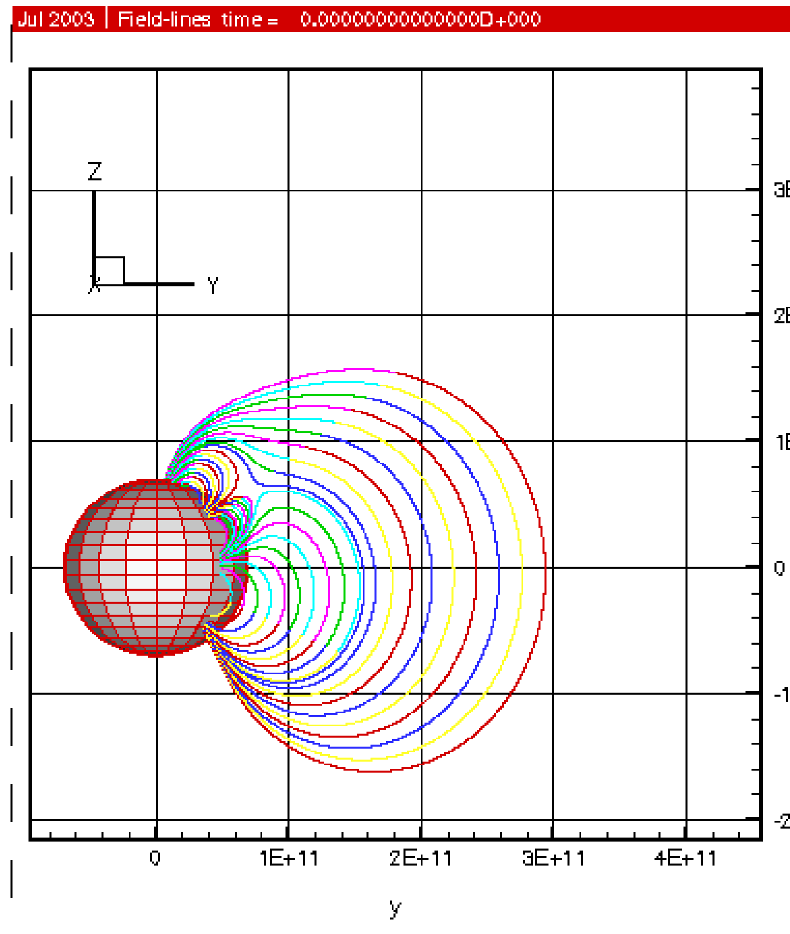
- Potential magnetic fields and linear force free fields are popular due to their mathematic simplicity and available data. (e.g. from MDI on SOHO, Kitt Peak)
- Nonlinear force free fields are necessary to describe active regions exactly. More challenging both observational and mathematical.
- A consistent 3D model of the solar corona requires tomographic inversion and magnetic reconstruction in one model.

# NRL: MHD 2.5D Spherical Breakout

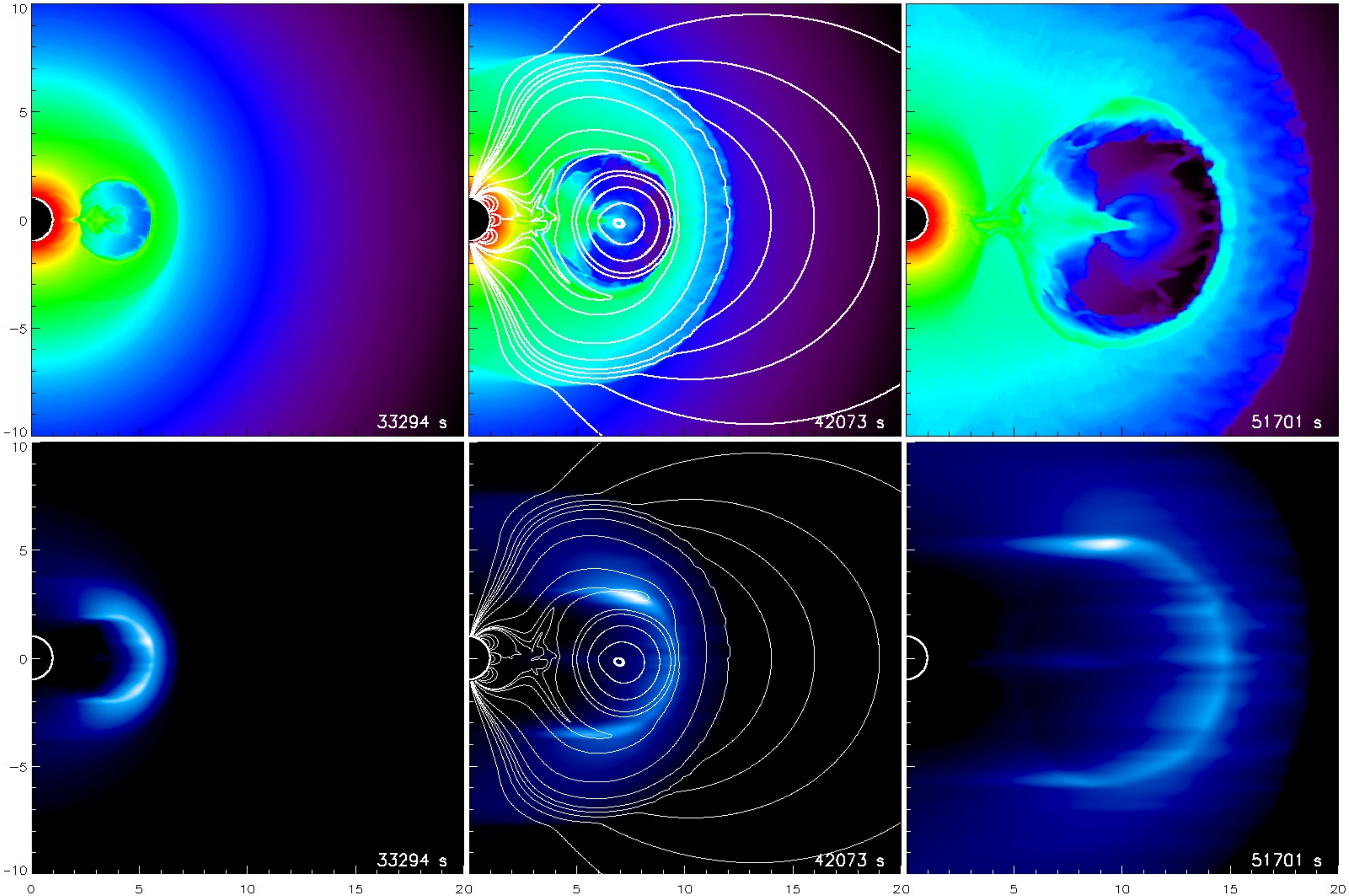
P. J. MacNeice et al, ApJ, in press – properties of model

comparison with

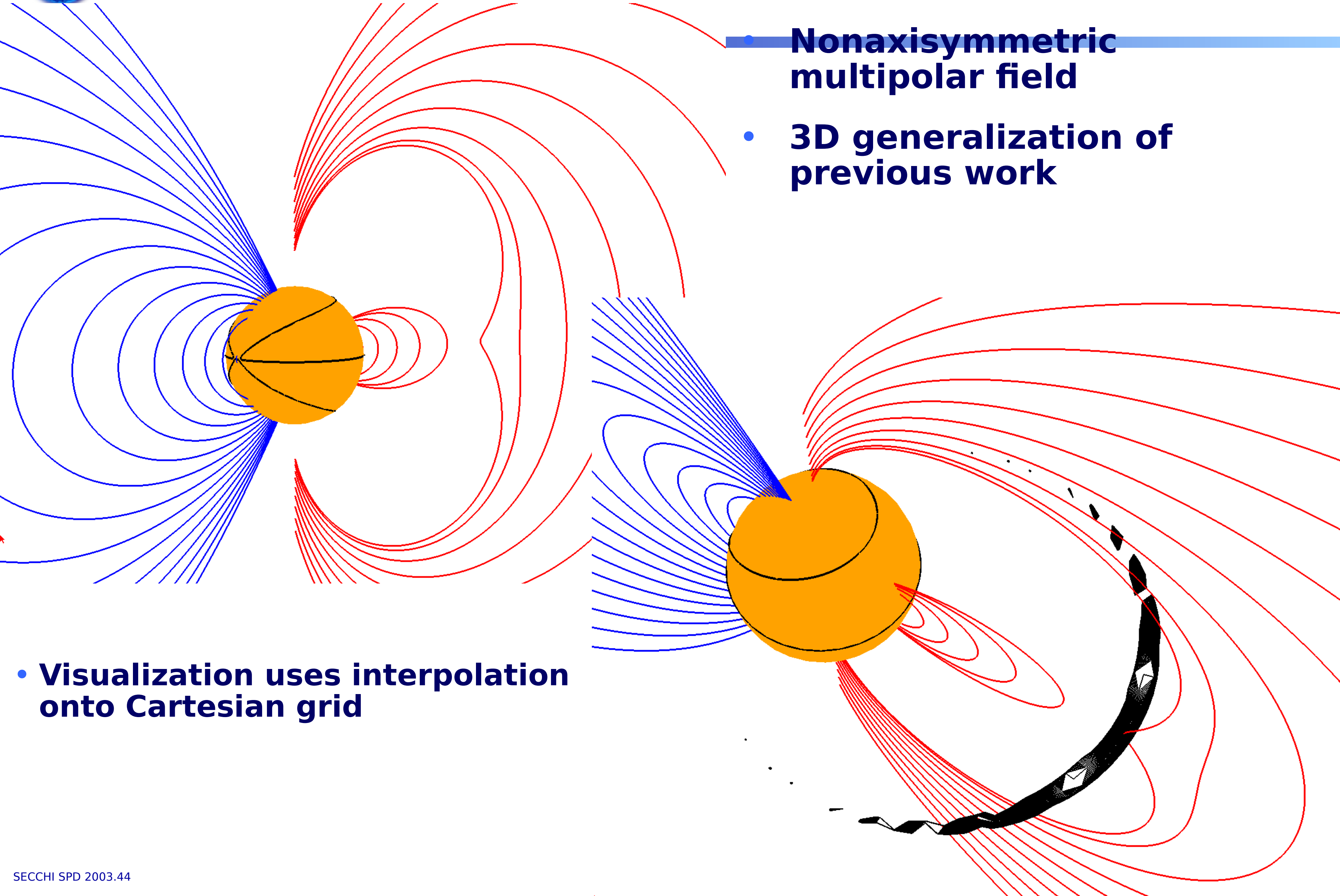


# NRL: MHD: Density (top), Brightness (bottom)

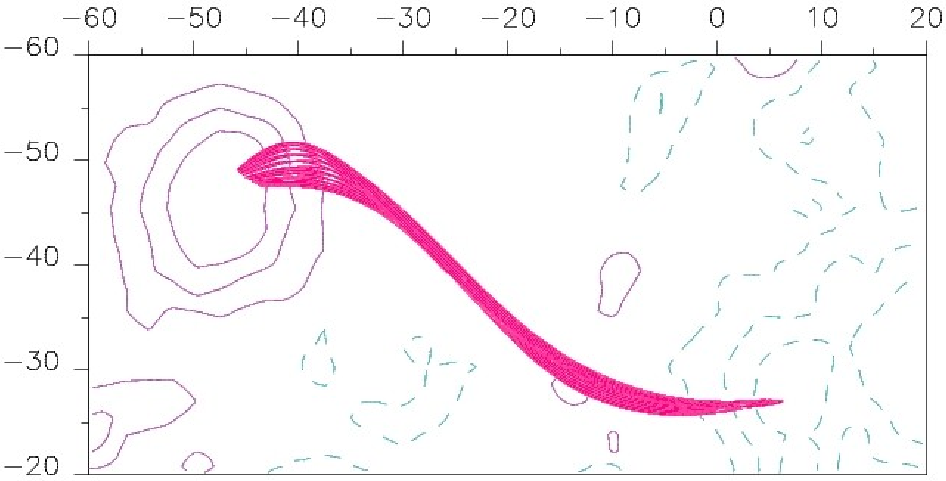


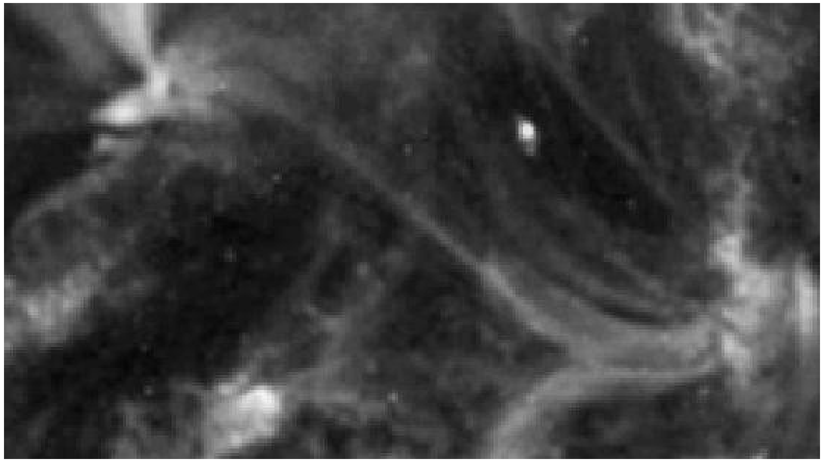
# NRL: MHD: 3D Spherical Breakout

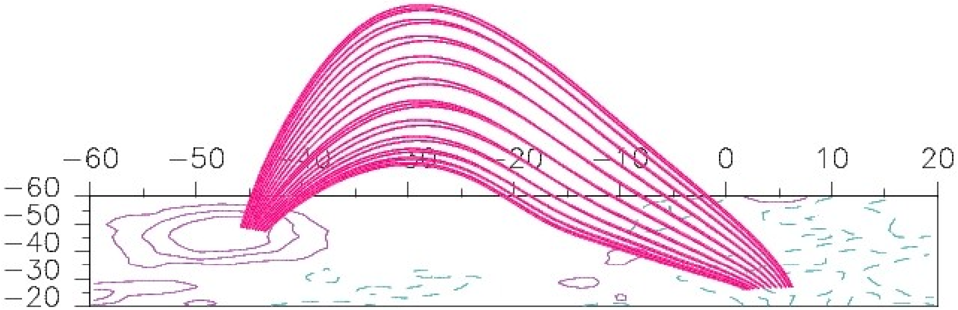


- **Nonaxisymmetric multipolar field**
- **3D generalization of previous work**
- **Visualization uses interpolation onto Cartesian grid**

# NRL: MHD: Corona Loop Structure



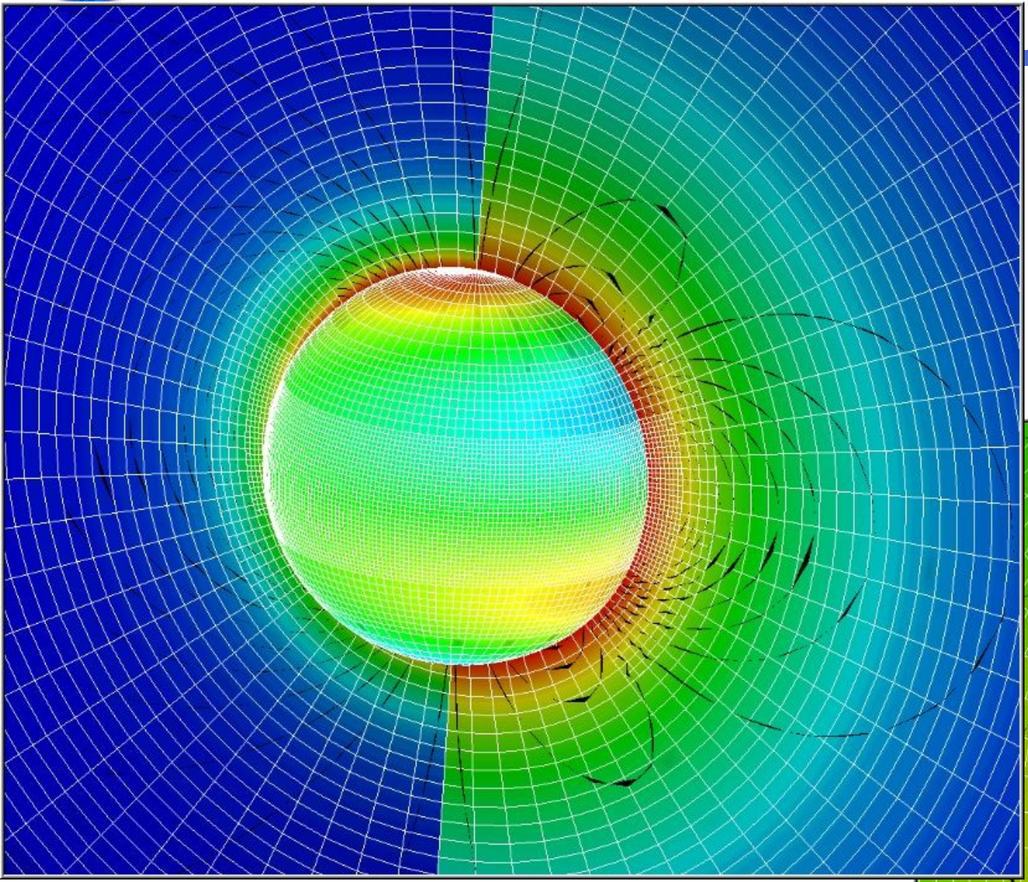





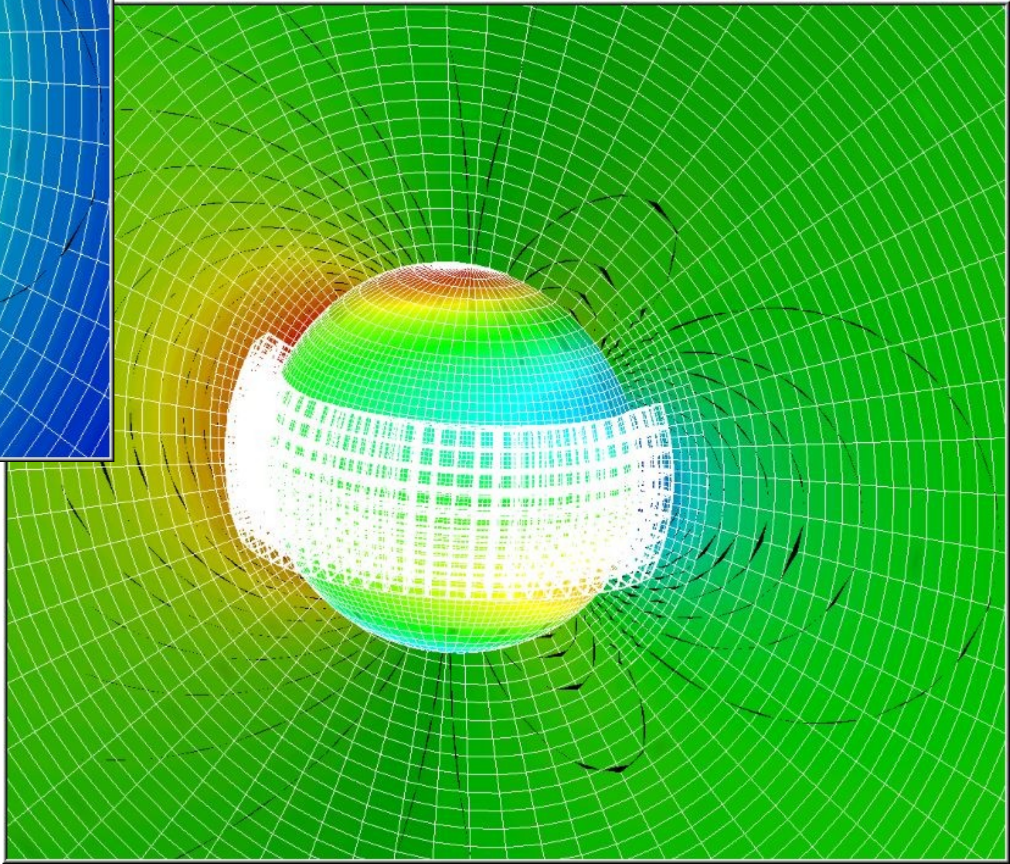

TRACE 171 Image
Extrapolated Flux Tube

Lopez-Fuentes & Klimchu

# NRL: MHD: 3D Spherical Breakout



- **B_radial, flux, density, temperature**



- **B_radial, flux, grid**

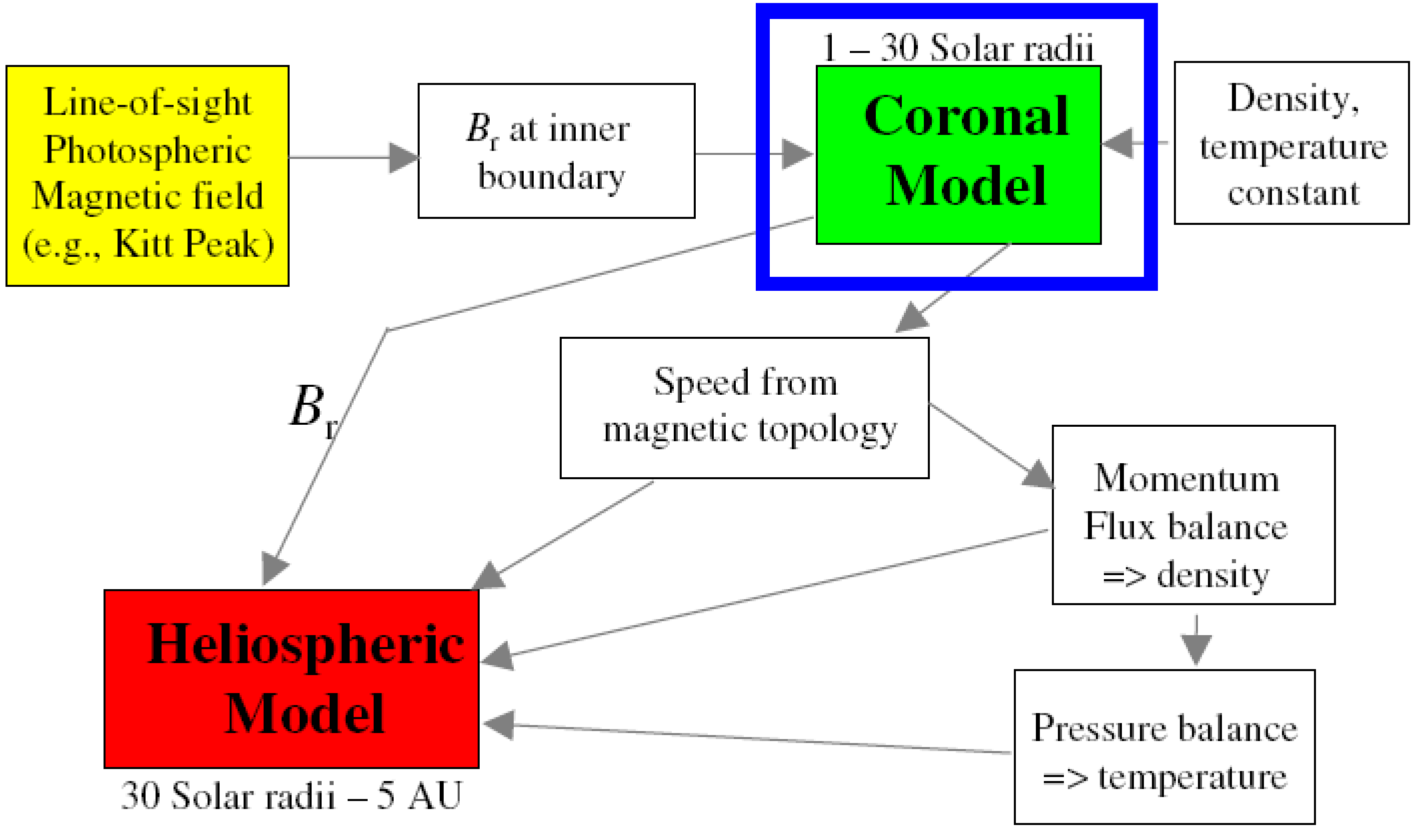
# SAIC: MAS Model Highlights

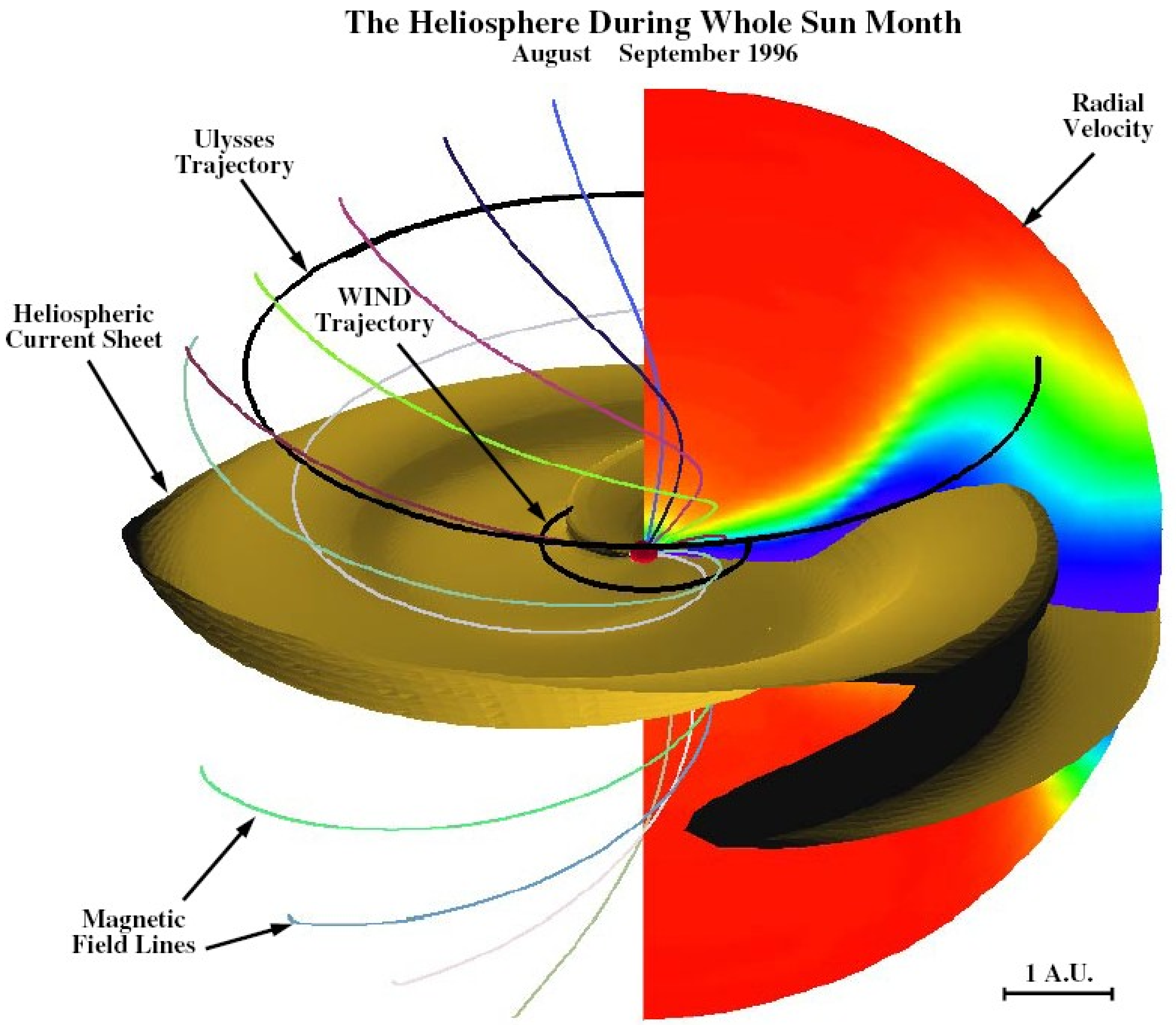
- MAS has been around for ~ 13 years
- It is built on a rich base of experience in computational physics and the modeling of solar coronal and fusion plasmas
- Features:
  - Time-dependent resistive MHD
  - Incorporation of observed photospheric magnetic field data
  - Evolution of boundary data
  - Coronal and heliospheric components
  - Non-uniform meshes (structured)
  - 3D finite differences in spherical $(r,\theta,\phi)$ coordinates
  - Implicit and semi-implicit time differencing
  - Comprehensive physics model including the solar wind and energy transport (radiation, parallel thermal conduction, heating, and Alfvén waves)
  - Has been used to model CMEs

# SAIC: MAS Model Highlights (cont.)

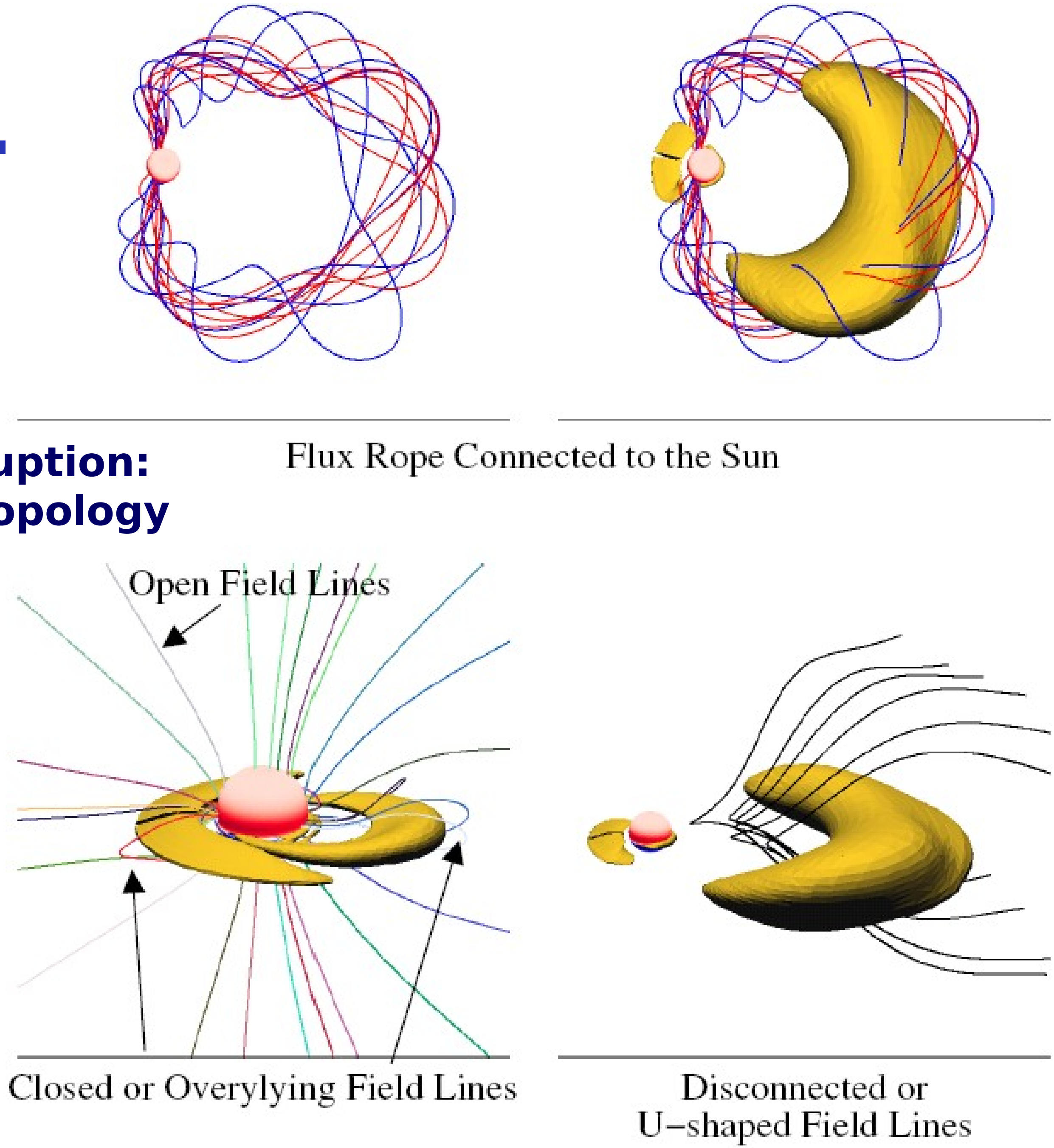
- Written in FORTRAN 90
- Designed to run on massively parallel computers using MPI
  - Linux & Beowulf (lf95, pgf90, Intel Fortran)
  - Mac (Absoft and xlf)
  - IBM/SP3 (xlf)
- Mesh decomposition among processors in 3D
- Dynamic allocation allows mesh size and number of processors to be selected at run time
- Restart capability using HDF files (for long runs)
- Many applications and comparisons with observational data (eclipses, IPS, *in situ* solar wind measurements, coronal holes, pB images, current sheet topology and spacecraft crossings, CMEs)
- A rich set of post-processing tools has been developed

# SAIC: MHD Model of the Corona and Heliosphere




The Heliosphere During Whole Sun Month
August September 1996
Radial Velocity
Ulysses Trajectory
WIND Trajectory
Heliospheric Current Sheet
Magnetic Field Lines
1 A.U.

## SAIC: 3D CME Eruption: Magnetic Field Topology



# The Community Coordinated Modeling Center

CCMC

NASA AFMC AFOSR AFRL AFWA NOAA NSF ONR


- Concept of Operations
- Agency Partners
- Steering Committee
- GSFC Staff
- Workshops and Meetings
- Presentations and Publications
- Space Weather Models
- Simulation Results
- Special Sun-Earth Connection Events
  - New SHINE Campaign Events
  - New October 2003 Events
- New Experimental Real-time Simulations
- Runs on Request
- Submit Model
- Space Weather Metrics
- Frequently Asked Questions
- Comments and Questions



Email CCMC

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- Space Weather Metrics
- Frequently Asked Questions
- Comments and Questions

Curator: Ms. Ayris Falasca
NASA Official: Dr. Michael Hesse

Privacy, Security, Notices


# CCMC Space Weather Models

- The CCMC works with the research community on the creation of advanced–capability space research models, focusing on space weather applications.
- In support of space science research the CCMC provides, to the research community, the results of selected runs and all runs–on–request.
- The CCMC requests customer feedback on the scientific use and viability of model results made available here.
- If results from runs–on–request are used in a scientific publication or presentation the CCMC requests that, at a minimum, the authors acknowledge the CCMC and the originators of the computational model. All users should contact the code developers for the purpose of publication. You may wish to offer co–authorship, or model owners may request co–authorship at their discretion.

  *In addition, for tracking purposes for our government sponsors, we ask that you notify the CCMC whenever you use CCMC results in a scientific publication or presentation*

## Solar Models

- MAS – developed by J. Linker, Z. Mikic, R. Lionello, and P. Riley
- PFSS – developed by J. Luhmann et al.

## Heliosphere Models

- Heliospheric Tomography – developed byB. Jackson and P. Hick
- Exospheric Solar Wind Model – developed by H. Lamy and V. Pierrard

## Global Magnetosphere Models

- BATS–R–US – developed by the Center for Space Environment Modeling (University of Michigan)
- UCLA–GGCM – developed by Jimmy Raeder

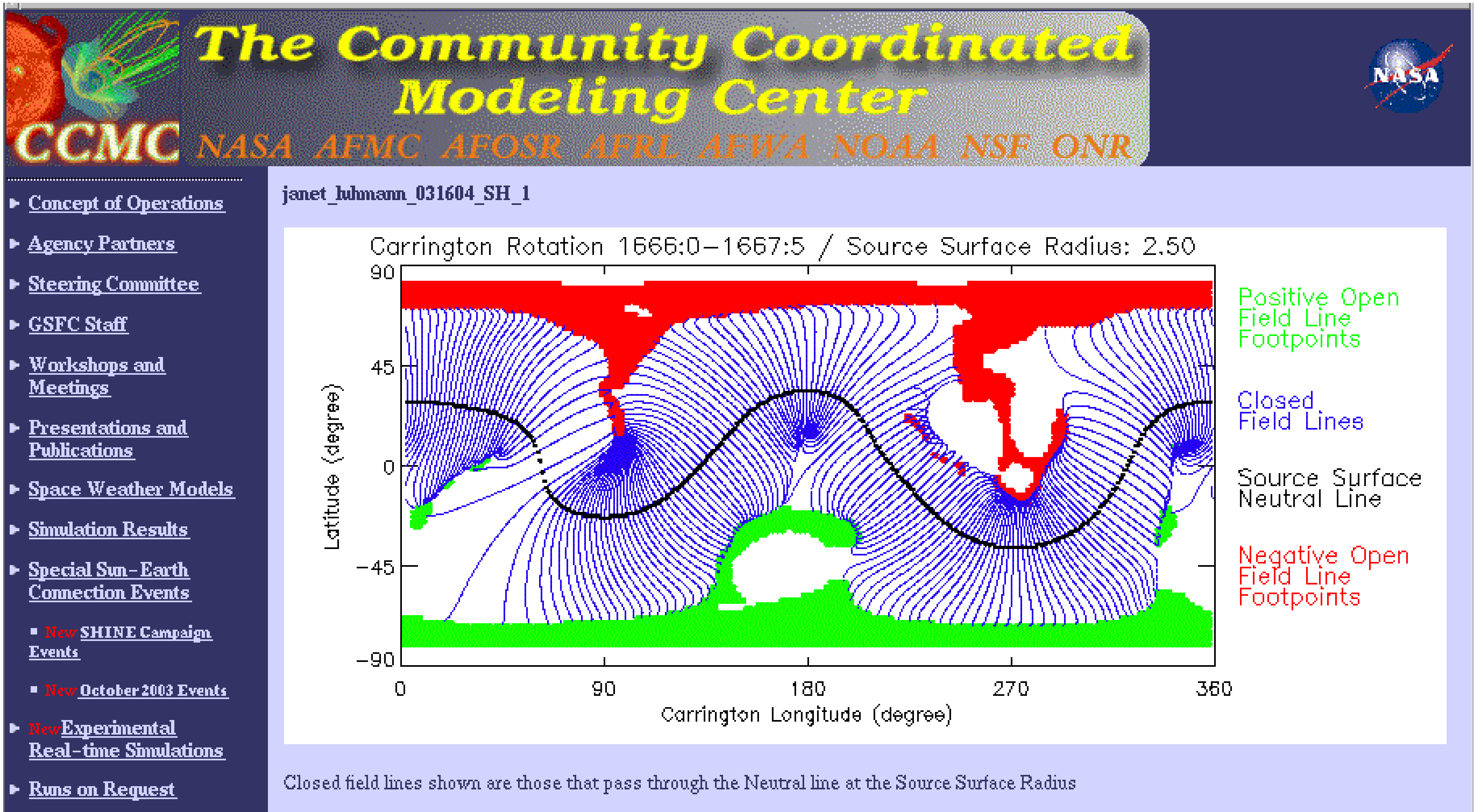
## Inner Magnetosphere Models

- Fok Ring Current/Radiation Belt Model – developed by Mei–Ching Fok

## Ionosphere/Thermosphere Models

- SAMI2 – developed by Joe Huba and Glenn Joyce
- Weimer–2K – developed by Daniel Weimer
- CTIP – developed by Timothy Fuller–Rowell

# Synoptic Map



# Heliospheric Imager (HI)

# Heliospheric Imager

- HI Operations Document – R. Harrison
- HI Image Simulation – C. Davis & R. Harrison
- HI Operations Scenarios – R. Harrison & S. Matthews
- HI Beacon Mode Specification – S. Matthews

THE UNIVERSITY OF BIRMINGHAM

CCLRC Rutherford Appleton Laboratory

CSL

# Heliospheric Imager

- HI in a nutshell:

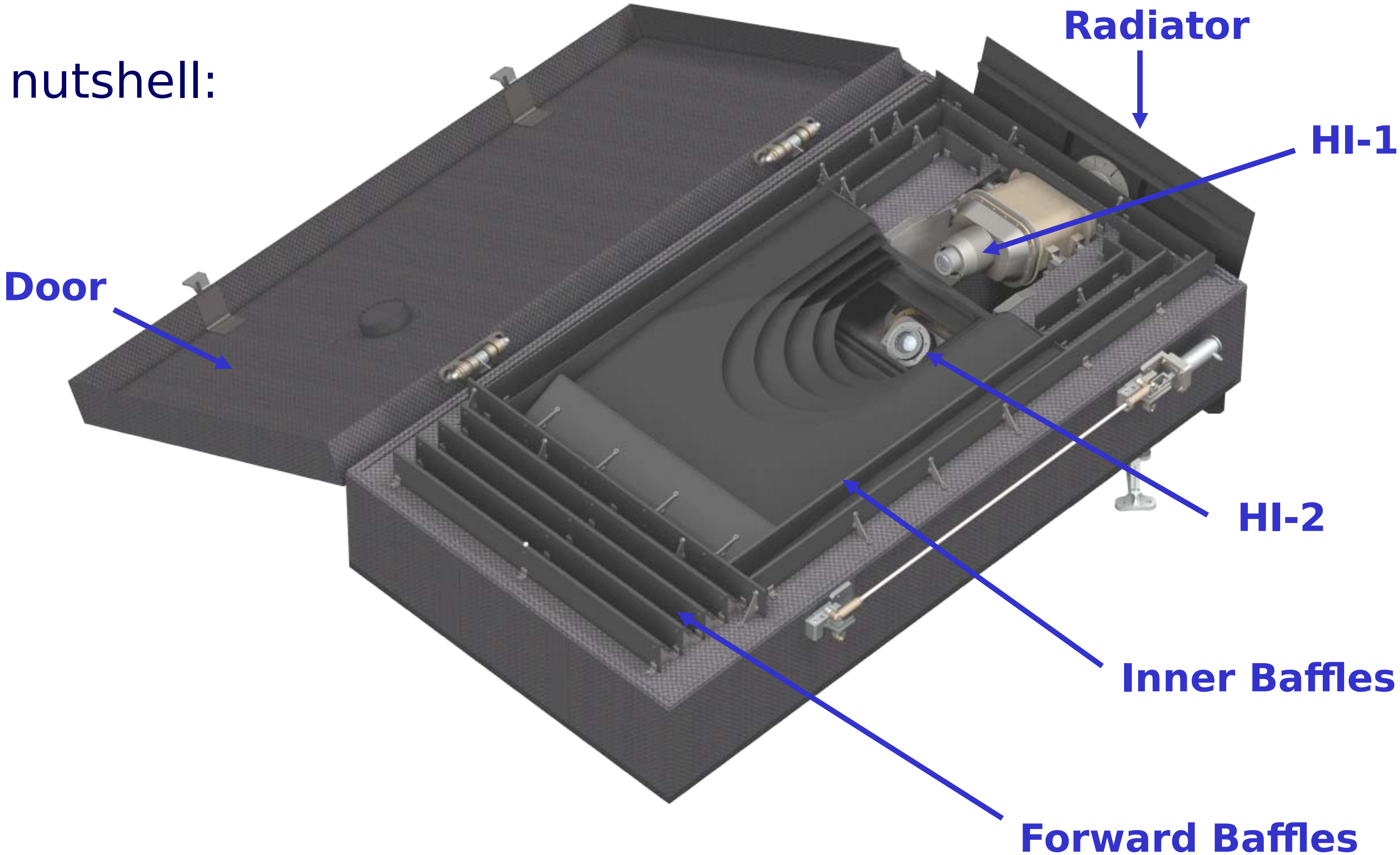
First opportunity to observe Earth-directed CMEs along the Sun-Earth line in interplanetary space - the first instrument to detect CMEs in a field of view including the Earth!

First opportunity to obtain stereographic views of CMEs in interplanetary space - to investigate CME structure, evolution and propagation.

Method: Occultation and baffle system, with wide angle view of the heliosphere, achieving light rejection levels of $3x10^{-13}$ and $10^{-14}$ of the solar brightness.

# Heliospheric Imager

- HI in a nutshell:



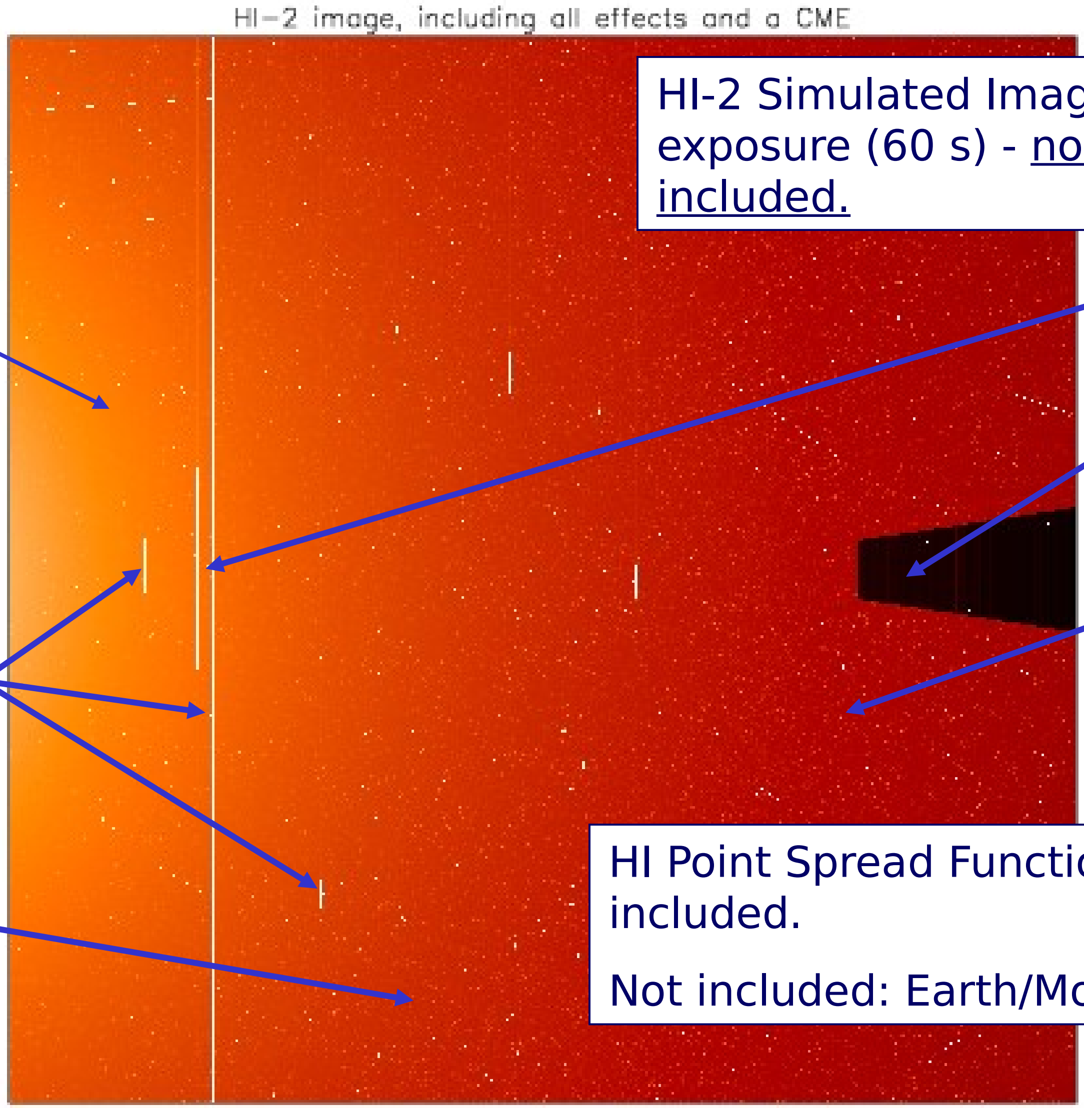
# Heliospheric Imager

| ***Study*** | ***Author*** |
| --- | --- |
| Synoptic CME programme | R. Harrison |
| Beacon mode | Matthews, Harrison, Davis |
| Impact of CME on Earth | R. Harrison |
| Understanding how observations at L1 & SECCHI are related | P. Cargill |
| CMEs in interplanetary space | P. Cargill |
| 3-D structure of interplanetary CMEs | L. Green |
| CME onset | S. Matthews |
| Particle acceleration at CME shocks | S. Matthews |
| The relationship between CMEs and magnetic clouds | S. Matthews |
| Boundary regions between fast & slow streams in the solar wind | A. Breen |
| Development of co-rotating interaction regions | A. Breen |
| Solar wind microstructure | A. Breen |
| Differential drift velocities in the fast & slow solar winds | A. Breen |
| Remote solar wind measurements from 3-D obs. of cometary ion tails | G. Jones |
| Interplanetary acceleration of ICMEs | M. Owens |

# HI – Image Simulation

The story so far...

HI-2 Simulated Image - nominal exposure (60 s) - non-shutter effect included.




F-corona & stray light

Planets

HI2 Occulter

Stellar ‘background’ down to 13th mag.

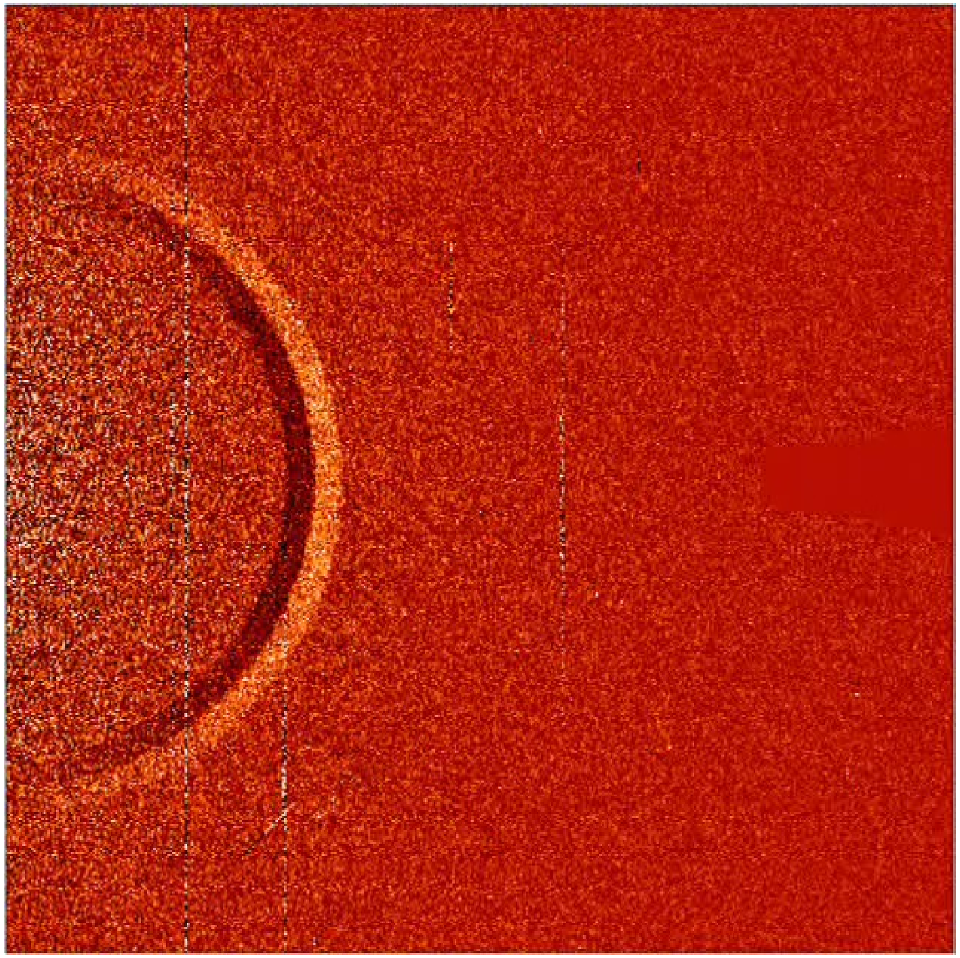
Saturation of brightest planets & stars

Cosmic rays

HI Point Spread Function & noise included.

Not included: Earth/Moon

# HI- Simulation Movies



512 x 512

# Considerations – HI FOV, CMEs

1) HI common volume observed highly dependent on angular position (mission duration).
2) Temporal confusion from voxels whose emission observed at the CCDs originates at different times: light travel time differences across the field of view.
3) Both of the above optimal with Earth directed plasma
4) CME speed = 800 km/s vs. summed exposure time
   a) Voxel identification confusion in reconstructions with temporal development
   b) Resolution of features: approximately the number of pixels crossed in HI summed individual exposures.
      i. HI-1 (35”/pixel) => 30 min. summing, 36x36 pixels (Sun-Earth line, 45º velocity)
      ii. HI-2 (120”/pixel) => 60 min. summing, 32x32 pixels (Sun-Earth line, 90º velocity)

# SMEI Early Results

GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L02802, doi:10.1029/2003GL018766, 2004

## Tracking a major interplanetary disturbance with SMEI

S. J. Tappin,[1] A. Buffington,[2] M. P. Cooke,[1] C. J. Eyles,[1] P. P. Hick,[2] P. E. Holladay,[3] B. V. Jackson,[2] J. C. Johnston,[3] T. Kuchar,[4] D. Mizuno,[4] J. B. Mozer,[3,5] S. Price,[3] R. R. Radick,[3,5] G. M. Simnett,[1] D. Sinclair,[3] N. R. Waltham,[6] and D. F. Webb[4]

Received 3 October 2003; revised 8 December 2003; accepted 22 December 2003; published 22 January 2004.

[1] We present the first clear observations of an Earth-directed interplanetary disturbance tracked by the Solar Mass Ejection Imager (SMEI). We find that this event can be related to two halo CMEs seen at the Sun about 2 days earlier, and which merged in transit to 1 AU. The disturbance was seen about 16 hours before it reached Earth, and caused a severe geomagnetic storm at the time which would have been predicted had SMEI been operating as a real-time monitor. It is concluded that SMEI is capable of giving many hours advance warning of the possible arrival of interplanetary disturbances. *INDEX TERMS:* 2194 Interplanetary Physics: Instruments and techniques; 2788 Magnetospheric Physics: Storms and substorms; 7513 Solar Physics, Astrophysics, and Astronomy: Coronal mass ejections. **Citation:** Tappin, S. J., et al. (2004), Tracking a major interplanetary disturbance with SMEI, *Geophys. Res. Lett.*, *31*, L02802, doi:10.1029/2003GL018766.

### 1. Introduction

[2] The Solar Mass Ejection Imager (SMEI) [*Eyles et al.*, 2004] was designed to observe interplanetary disturbances propagating from the Sun, and to demonstrate the feasibility of using such observations as a tool for space weather forecasting.

[5] Although the methods of subtracting stars and zodiacal light and of eliminating satellite tracks and particle interactions in the CCDs are as yet at an early stage of development, it is still possible to detect heliospheric plasma by subtracting a pre-event background image.

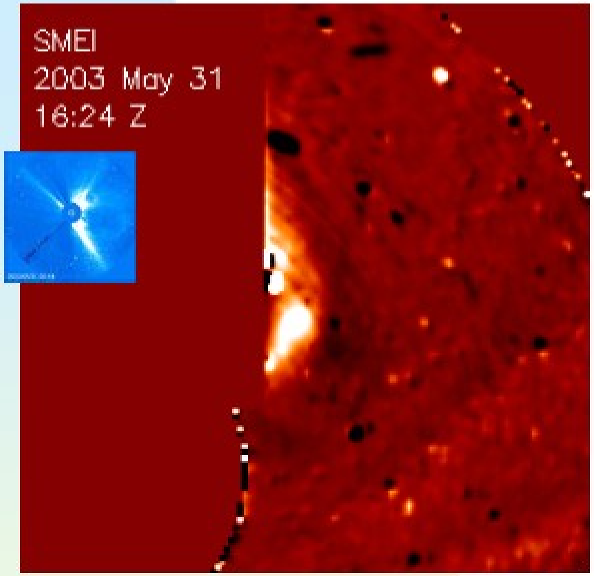
[6] In this letter we describe how a major disturbance was tracked from 0.6 to 1 AU. We also show that the properties of this disturbance are confirmed by measurements from other sources, but that the SMEI observations are able to add information not obtainable from any other source.

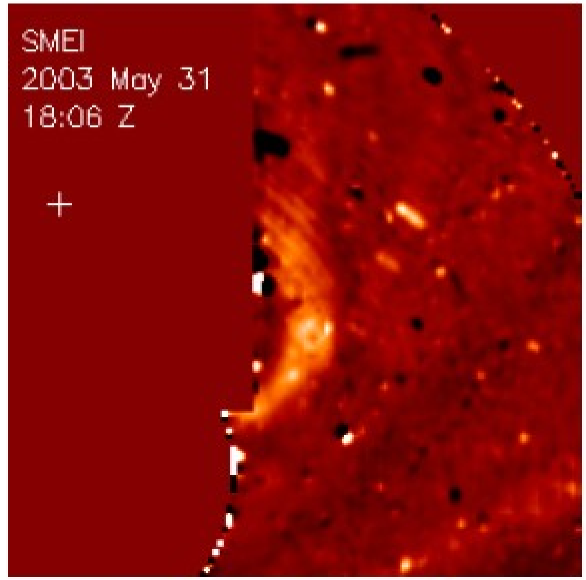
### 2. The Observations

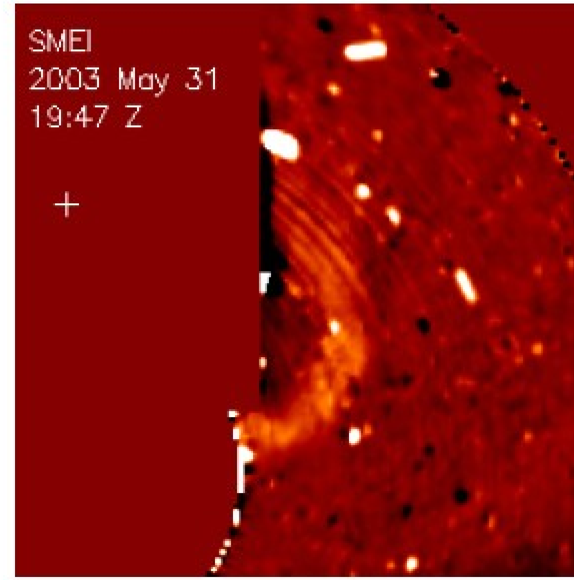
[7] Each of the 3 SMEI cameras captures an image of its $60^\circ \times 3^\circ$ field of view every 4 seconds. These CCD images are transmitted back to Earth where they are assembled to produce all-sky maps of the brightness in white light of the sky. These maps, which are the primary data product from SMEI, have a resolution of approximately $1^\circ$ in an Aitoff-Hammer equal-area projection, currently these are not converted to physical units but are in instrument analog-digital converter units (ADU). A given point in the sky takes about one minute to cross the field of view of a SMEI camera, and the $1^\circ$ pixels in the Aitoff maps are larger than

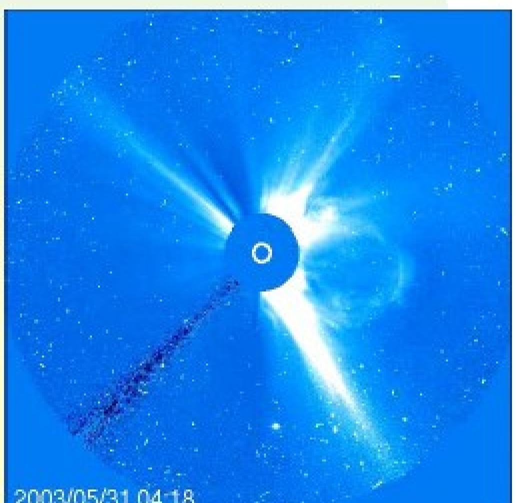
# The Solar Mass Ejection Imager Mission

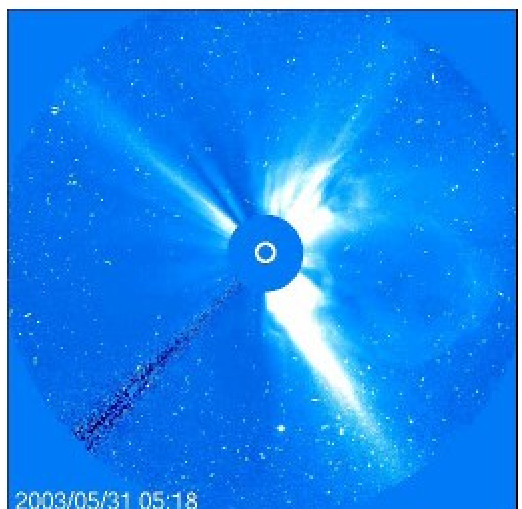
## SMEI CMEs




CME on May 31, 2003 - LASCO observed the CME travelling at ~2000 km/sec. SMEI observes a speed of from 1250 to 1800 km/sec. (SMEI images courtesy of AFRL)

# IPS – Thomson Scattering Modeling

## The Solar Mass Ejection Imager Mission

**B. V. Jackson, A. Buffington, P. P. Hick**
*Center for Astrophysics and Space Sciences, University of California at San Diego, LaJolla, CA.*

**R.C. Altrock, P.E. Holladay, J.C. Johnston, S.W. Kahler, J.B. Mozer, S. Price, R.R. Radick, R. Sagalyn, D. Sinclair**
*Air Force Research Laboratory/Space Vehicles Directorate (AFRL/VS), Hanscom AFB, MA*

**G.M. Simnett, C.J. Eyles, M.P. Cooke, S.J. Tappin**
*School of Physics and Space Research, University of Birmingham, UK*

**T. Kuchar, D. Mizuno, D.F.Webb**
*ISR, Boston College, Newton Center, MA*

**P.A. Anderson**
*Boston University, Boston, MA*

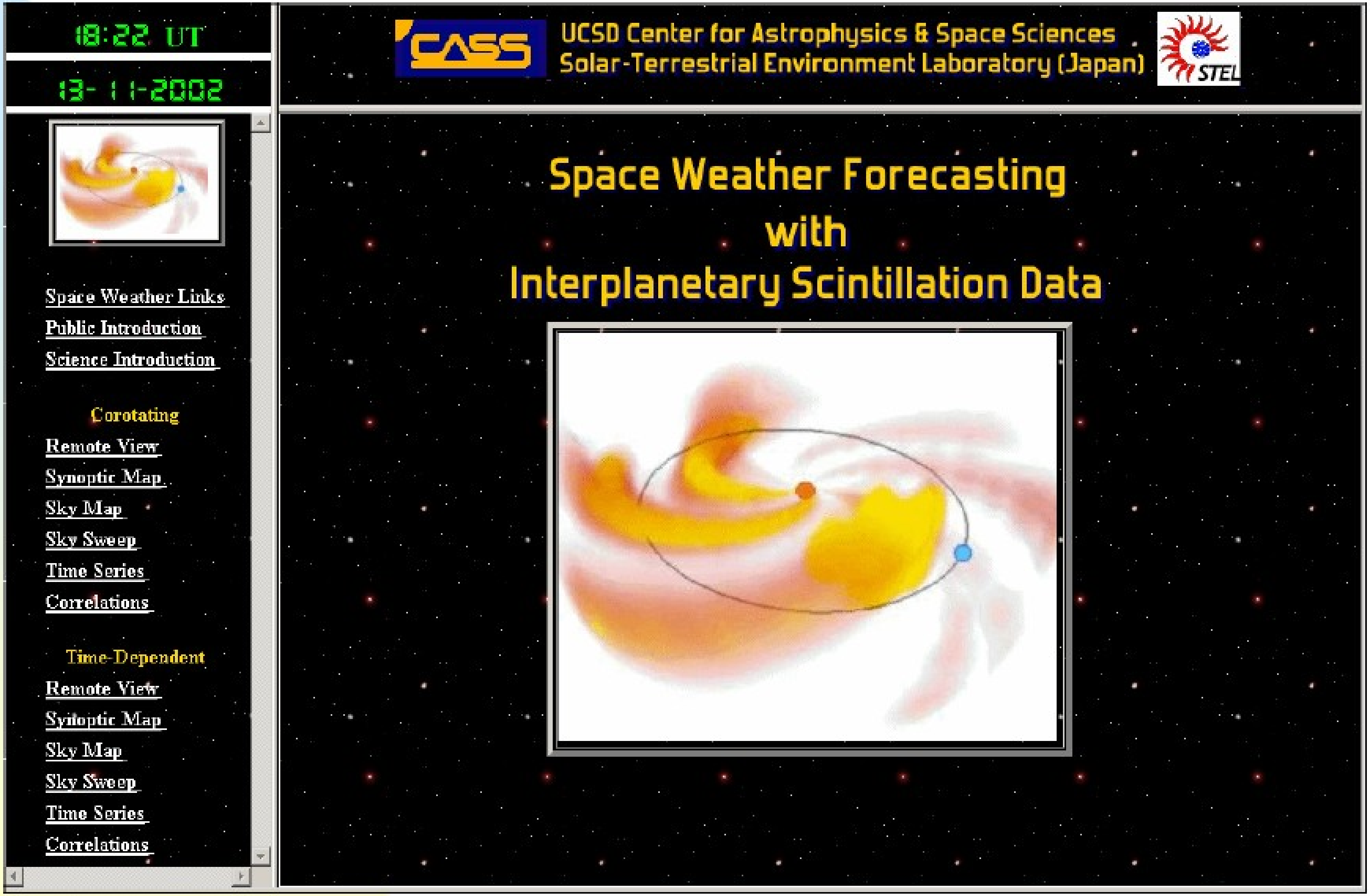
**S.L. Keil**
*National Solar Observatory, Sunspot, NM*

**R.E. Gold**
*Johns Hopkins University/Applied Physics Laboratory, Laurel, MD*

**N.R. Waltham**
*Space Science Dept., Rutherford-Appleton Laboratory, Chilton, UK*

# IPS – Thomson Scattering Modeling

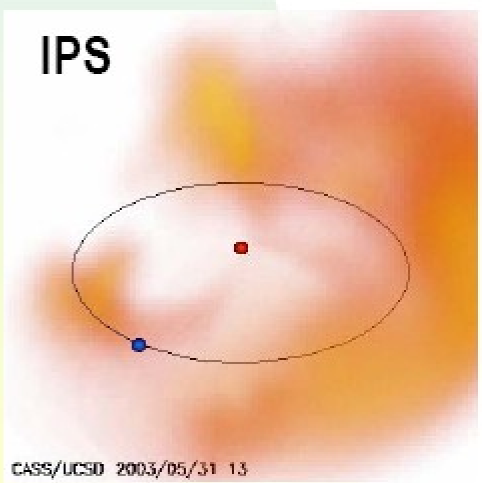
http://casswww.ucsd.edu/solar/forecast/index_v_n.html

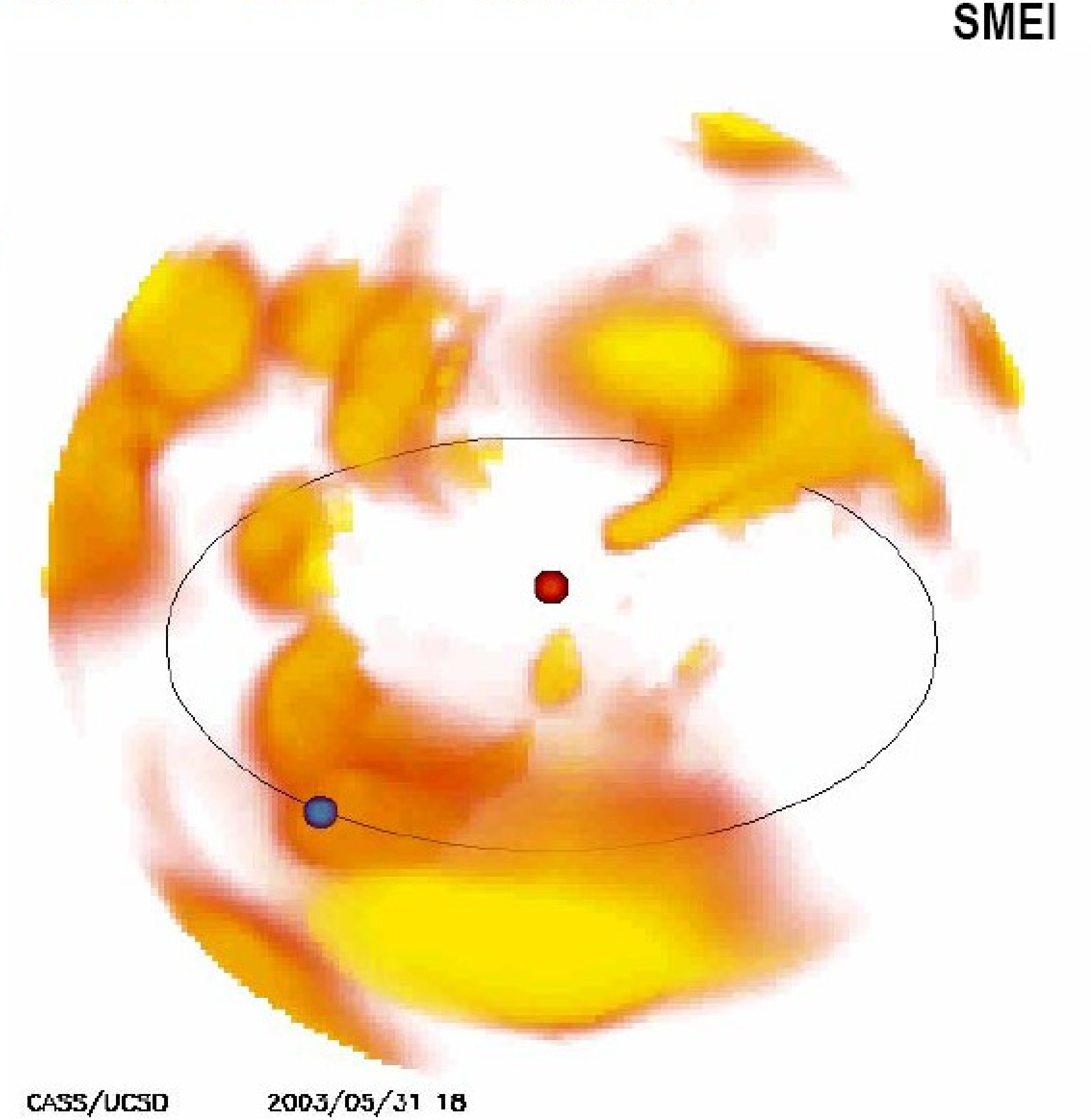


# The Solar Mass Ejection Imager Mission

# Solar Wind CAT-scan

Time-dependent tomographic analysis of the solar wind using SMEI data during the May 28, 2003 CME.



# Conclusions

- **Useful 3D reconstructions are achievable!**
- **There are real limitations that we must understand and that will define which reconstructions are possible.**
- **The reconstructions are significantly improved with the addition of a third viewpoint to the reconstruction, such as could be provided during the STEREO mission by an operating LASCO coronagraph on the SOHO spacecraft.**
- **Application to SECCHI will require substantial effort and collaboration; we appreciate all help on scientific preparations.**
  - **Funding?**
- **Web Site: http://stereo.nrl.navy.mil/ (follow link to 3D R&V). This contains past presentations and all necessary details to test reconstruction methods on sample problems.**

# BACKUP SLIDES

# 3-D Reconstruction Using the Pixon Method

- The problem is to invert the integral equation with noise:

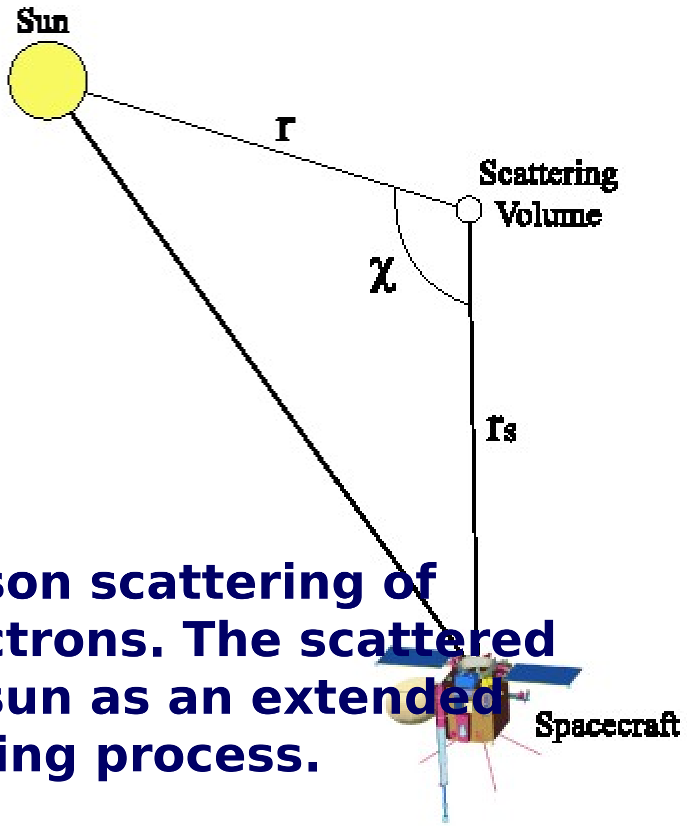
$$D_n(\mathbf{x}) = \int \mathbf{d}^3\mathbf{r} H_n(\mathbf{x},\mathbf{r}) n(\mathbf{r}) + N_n(\mathbf{x})$$

- But there are many more model voxels than data pixels.
- And the reconstruction significantly amplifies the noise.
- All reconstruction methods try to overcome these problems by restricting the model; they differ in how they do that.
- A good first restriction is non-negative n(r).

  ⇒ Non-Negative Least-Squares (NNLS) fit.
- Minimum complexity (Ockham’s razor): restrict n(r) by minimizing the number of parameters used to define it.
- The number of possible parameter combinations is large.

  ⇒ An exhaustive parameter search is not possible.
- The Pixon method is an efficient iterative procedure that approximates minimum complexity by finding the smoothest solution that fits the data (details: Puetter and Yahil 1999).
- New modification: Adaptive (Hierarchical) Gridding

# K-Corona Physics: Thomson Scattering

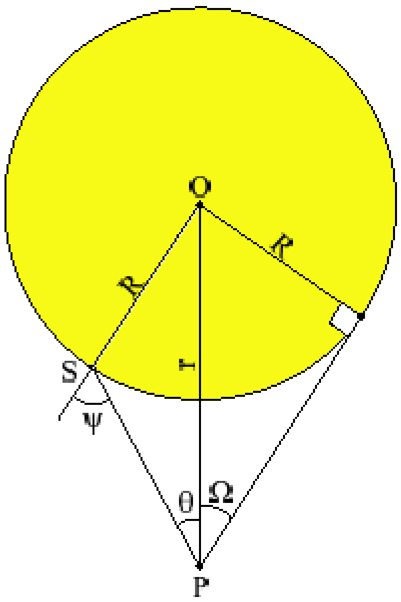



**K-corona arises from Thomson scattering of Photons by hot coronal electrons. The scattered radiation is polarized. The sun as an extended source modifies the scattering process.**

# K-Corona Physics: Emission Coefficients

**Separate scattered radiation into tange and radially polarized light. The tangen emission coefficient (ph $s^{-1}$ $cm^{-3}$ $sr^{-1}$ ) m written as:**

$$\epsilon_t(r) = \frac{\pi I_0 \sigma}{2}\, n_e(r)\, \Sigma_A$$




**And the radial emission coefficient is:**

$$\epsilon_r(r) = \frac{\pi I_0 \sigma}{2}\, n_e(r)\, \left(\Sigma_B\ \cos^2(\chi_s) + \Sigma_C\right)$$

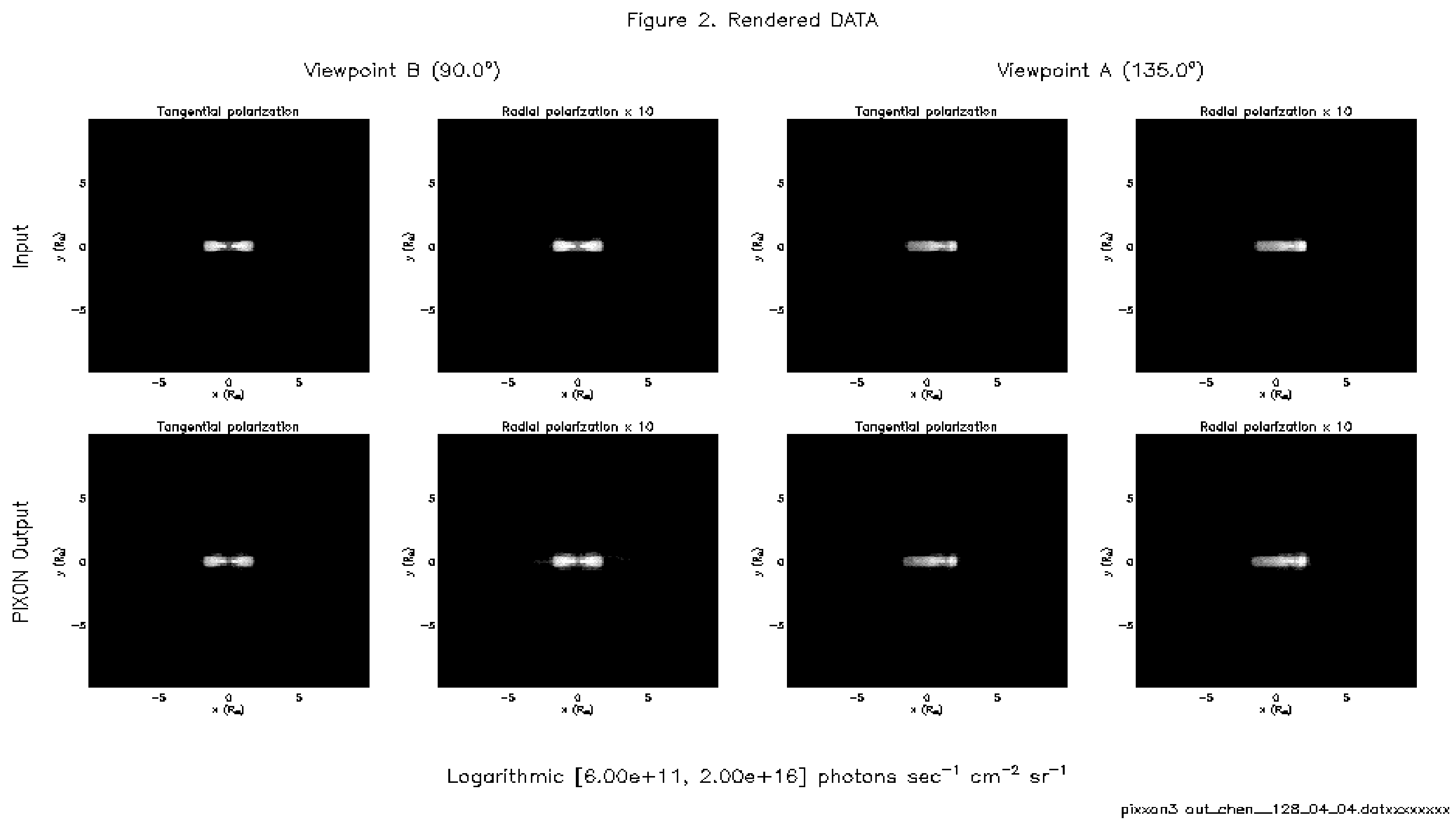
**Where we explicitly account for extended sun limb darkening**

# PIXON: Adaptive (Hierarchical) Gridding

- **Naïve voxel size at the resolution of the projected detector pixels results in $10^9$ voxels.**
- **This is computationally unmanageable (or at least very time consuming).**
- **The number of voxels greatly exceeds the number of independent data points, which is only $4 \times 10^6$.**
- **We propose to solve both problems by using a hierarchical 3-D grid, which is coarse where the (projected) data show** n(r) **to be smooth and is progressively refined where the data require** n(r) **to be more structured.**
- **While the Pixon method does not require an adaptive grid, it can take advantage of it in imposing maximum smoothness to increase computational speed by a more efficient calculation.**

# 3D Reconstruction: CME model (J. Chen)

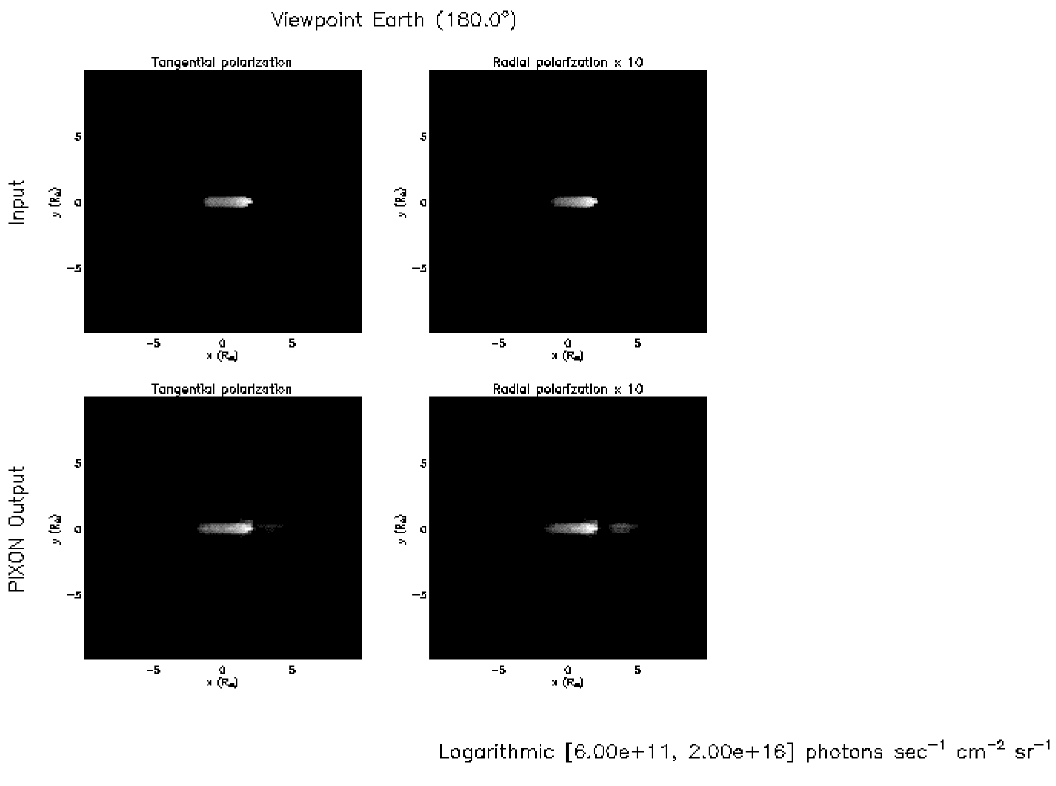
# Three Ecliptic Viewpoints: Rendered



# 3D Reconstruction: CME model (J. Chen)

## Three Ecliptic Viewpoints: Rendered

Figure 2. Rendered DATA



# 3D Reconstruction: CME model (J. Chen)

## 37° Spacecraft Separation